Protocol for Irrigation of Shrubs During Establishment: Establishing Best Management Irrigation Practices for Shrub Establishment in Florida Landscapes

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Executive Summary

The objective of this project was to determine how best to irrigate shrubs during establishment in Florida residential and commercial landscapes. This three part project was executed from 2003 through 2009 at four locations in Florida (Ft. Lauderdale, Balm, Apopka and Citra, Florida). Locations represented three water management districts and most climatic zones in the state. Twenty-seven species were planted at 10 points in time over the course of 4 years. Irrigation was applied in various volumes and frequencies to determine the minimum required for establishing shrubs with acceptable quality. Irrigation requirements for Florida native and non-native shrub establishment were compared.

A preliminary study (Study A) conducted on 3 shrub species established that 3 liters of water applied per irrigation event was an acceptable volume for establishing 3-gallon container grown shrubs into the landscape. An additional preliminary study conducted under a rain shelter (Study B) confirmed the need for regular irrigation (3L) applied every 4 days to keep shrubs alive when rainfall was eliminated. Phase one (Study C) established an effective irrigation frequency for shrub establishment in the landscape using 3 liters of water on a total of 7 shrub species: every 4-8 days in north and central Florida and every 2-4 days in south Florida. Additionally, phase one determined that, under normal rainfall conditions, regular irrigation could be discontinued once shrub roots reached the edge of the canopy, however, irrigation was required in dry weather during the next 18 months to fully ensure survival. Phase two (Study D) confirmed the effectiveness of irrigation frequencies established in Study C on 12 additional shrub species in the landscape (6 native and 6 non-native shrub species) at each of 3 locations in the state. A total of 10 Florida native shrubs and 11 non-native shrubs were evaluated. There were no differences between native and non-native species. We verified the point at which regular irrigation could be discontinued under normal rainfall conditions for 3-gallon shrubs in the Florida landscape. Finally, a lysimeter system (Study F) was designed, built and compared with shrubs installed in field plots (Study E) for evaluating water loss from landscape systems in future research.

Results of this 6-year study will help guide development of irrigation strategies for newly planted and establishing Florida landscapes.

Results–at–a–Glance

• Three liters irrigation volume was sufficient to establish all 27 species of shrubs planted from 3-gallon containers in this study.

• Irrigation frequency did not significantly affect shrub survival or quality (measured as canopy density and dieback).

• Shrubs grown in north Florida (hardiness zone 8b) could be established with 3 liters irrigation applied every 8 days under normal rainfall conditions, but increasing the irrigation frequency to every 2 days increased canopy growth for some species.

• Shrubs grown in central Florida (hardiness zone 9a) could be established with 3 liters irrigation applied every 8 days under normal rainfall conditions, but increasing the irrigation frequency to every 2 or 4 days increased canopy and root growth and canopy dry weight for some species. Irrigating at least every 4 days is recommended for survival when planting during extended dry periods.

• Shrubs grown in south Florida (hardiness zone 10b) could be established with 3 liters irrigation applied every 4 days under normal rainfall conditions, but increasing the irrigation frequency to every 2 days increased root growth, canopy dry weight, and root dry weight for some species. Irrigating at least every 4 days is recommended for survival when planting during extended dry periods.

• Shrub roots spread out to reach the edge of the foliage canopy between 12 and 104 weeks after planting depending on species.

• Occasional irrigation was required after regular irrigation was discontinued (12 to 22 weeks after planting) for up to 2 years after planting. Shrubs should therefore be monitored for symptoms of water stress during the first 2 years after planting and irrigated accordingly.

• There were no differences in growth or quality between native and non-native shrubs as a group at any irrigation frequency in any region of Florida.

• Survival of Viburnum was reduced to 50% by 16 weeks after planting when irrigated every 7 days under a rain shelter. This suggests that rainfall is needed to supplement irrigation at frequencies used in this study for some species.

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Introduction

Rapid growth in Florida's urban centers, coupled with frequent droughts, has led to water use restrictions throughout the state. Landscape irrigation has been one focus for the state's water restrictions. Many Florida water management districts limit irrigation for the establishment of newly installed plant material to a 30-60 day (d) period. However, current research indicates that plant material transplanted into the landscape from 11.4 liter (L) nursery containers may require 6 to 12 months to fully establish (Trenholm et al. 2002). A recent study conducted under a rainout shelter in Apopka, FL reported that *Viburnum odoratissimum* were established 16 weeks after planting (WAP) based on comparisons of cumulative water potential (S_{Ψ}) between stressed (nonirrigated) and unstressed (irrigated) *V. odoratissimum* (Scheiber et al., 2007). Reducing irrigation frequency from every 2 or 4 d to every 7 d delayed establishment of *Ilex cornuta* 'Burfordii Nana' by 4 to 8 weeks (Scheiber et al., 2007).

Water is one of the most limiting factors in establishing container-grown shrubs in the landscape. Immediately after installation (the establishment period), shrubs do not have a sufficient root system to compensate for the losses resulting from evapotranspiration without adequate irrigation (Barnett, 1986; Gilman et al., 1996; Montague et al., 2004). Inadequate irrigation during the establishment period can result in reduced root growth (Balok and Hilaire, 2002; Witherspoon and Lumis, 1986), vegetative growth (Shackel et al., 1997; Gilman and Beeson, 1996), and reproductive growth (Shackel et al., 1997). Newly installed shrubs receiving inadequate irrigation will likely have symptoms of drought stress, resulting in a decline in plant health and quality (Pittenger et al., 2001; Geisler and Ferree, 1984a) and eventually in plant death (Eakes et al., 1990; Geisler and Ferree, 1984a). This can result in significant economic losses to the landscaping industry, because companies often provide a guarantee on plant material for some time period following installation.

Recent research reported increased canopy and root growth during establishment in response to increased frequency of irrigation (Stabler and Martin, 2000; Marshall and Gilman, 1998; Gilman et al., 1996; Barnett, 1986). Canopy growth of *Ligustrum vulgare* increased to 4.9 ft^3 from 1.0 ft^3 when irrigation frequency was increased from every 10 d to every 5 d (Barnett, 1986). A similar growth increase occurred as irrigation frequency increased (every 2, 5, or 10 d) on *Caesalpinia pulcherrima* and *Cercidium floridum* (Stabler and Martin, 2000). Marshall and Gilman (1998) reported increased trunk diameter (5.8 cm vs. 4.7 cm), height (3.4 cm vs. 2.7 cm), and root mass (102.9 g vs. 52.5 g) of red maple as irrigation increased. Similarly, Harris and Gilman (1993) reported greater regenerated root dry weight and root volume when *Ilex* x *attenuata* 'East Palatka' was watered more frequently.

Irrigation frequency appears to be more important to tree establishment than the volume of irrigation applied. Gilman et al. (1998) found that irrigation volume (11, 22, or 33 L) did not significantly affect plant growth or stem water potential of *Quercus virginiana*, while reducing irrigation frequency resulted in reduced canopy and root growth of container grown trees compared to other production methods. Similarly, peach trees were reportedly more influenced by irrigation frequency (weekly or every 4 weeks) than by volume (1 x crop evapotranspiration (ET_c) or 1.5 x ET_c) during establishment. Trunk cross-sectional area of peach trees was reduced when irrigation frequency was reduced (Renquist, 1987). Additionally, an increase in irrigation volume (50, 75, or 100% replacement of actual water-use) did not result in increased growth of *Photinia* x *fraseri* (Welsh et al., 1991). However, environmental factors including soil type (Kjelgren et al., 2000; Barnett, 1986), species drought tolerance (Scheiber et al., 2008; Shaw and Pittenger, 2004; Pittenger et al., 2001; Kjelgren et al., 2000), and cultivar (Paine et al., 1992) may interact with irrigation frequency to influence establishment.

Water restrictions in Florida have increased interest in planting native shrub species because they are often touted as having lower water needs than non-native ornamental species. However, research indicates that water use is more likely to be a function of endemic habitat (Scheiber et al., 2008), shrub morphology (King and Wilson, 2006), and shrub maturity (Stabler and Martin, 2000) than its nativity. Scheiber et al. (2008) reported no differences in growth response or aesthetic appearance due to irrigation treatment for 8 native and 8 non-native species grown in north Florida. Only two species, which are endemic to swamps and streams, showed increased growth as a response to irrigation compared with no irrigation (Scheiber et al., 2008). Additionally, King and Wilson (2006) reported no differences between native and non-native species in response to irrigation compared to no irrigation, but did find differences between species as grouped by morphology. Forbs and graminoids showed a greater response to irrigation than woody and cryptogamic species (King and Wilson, 2006).

Most of the research on the effects of irrigation during establishment has been performed on trees. As a result, few guidelines for irrigation during shrub establishment have been developed. The objective of this study was to evaluate the impact of irrigation frequency, volume, and environmental conditions on shrub establishment.

Abstract
This multi phase project examined the effects of irrigation frequency and volume on quality, survival, and growth of 3-gallon (11.4 L) container grown shrubs during establishment in Florida landscapes. This project was executed from 2003 through 2009 at four locations in Florida (Ft. Lauderdale, Balm, Apopka and Citra, Florida representing most climatic zones in the state. Shrubs were planted from 2003-2006 into the landscape from 3-gallon containers and irrigation was applied at varying volumes (3, 6, or 9 L) and frequencies (every 2, 4, 7, or 8 days) depending on the phase of the study. Shrubs were successfully established by applying 3 L of water per irrigation event (58 L total) to the root ball and soil adjacent to the root ball at a frequency of every 8 days in north and central Florida and every 4 days in south Florida for a period of 20 weeks after planting. However, growth increases were seen with increased irrigation on some species, suggesting that optimal growth may be achieved during the first 2 years after planting when irrigation frequency in north and central Florida is increased to every 4 days and irrigation in south Florida is increased to every 2 days. Irrigating at least every 2 (South Florida) or 4 days (north and central Florida) is recommended for survival when planting during extended dry periods. Supplemental irrigation was required in north, central, and

south Florida after regular irrigation was discontinued (12-28 WAP depending on project phase). Supplemental irrigation was applied up to 2 years after planting only during extended periods of dry weather in order to maintain shrub survival. Additionally, the time needed to reach a root spread to canopy spread ratio of 1.0 when regular irrigation could be discontinued varied considerably between species (from 12 to 104 WAP). The occasional need for supplemental irrigation and the variability in growth rates between species suggest that irrigation needs during establishment are contingent upon species and rainfall conditions. Therefore, we recommend that all shrubs be monitored after regular irrigation is discontinued for symptoms of water stress for at least the first 2 years after planting.

Study A. Irrigation frequency and volume study. - Citra, FL

Materials and Methods

Ilex cornuta Lindl. & Paxt. 'Burfordii Nana', *Pittosporum tobira* Thunb. 'Variegata', and *Viburnum odorotissimum* Ker Gawl. obtained from a commercial nursery in 11.4 liter containers were planted May 27, 2004 into fine sand (Arredondo sand series) at the University of Florida's Plant Science Research and Education Unit in Citra, FL (USDA hardiness zone 9a). These three shrub species are commonly planted in the southern part of the US. Taxa were planted on 1.8 m centers with the top of the root ball positioned even with surrounding landscape soil. Circling roots at the edge of containers were not cut at planting in accordance with landscape industry practices. One plant of each species was randomly planted in each of the five blocks (15 plants total) in October 2003 (seven months before test plants were installed) in the same manner as test plants. These more established plants (called indicator plants) were irrigated with 9 L every 2 d for 9 months to encourage rapid establishment. Indicator plants were used to compare root to shoot ratios and stem water potential with the test plants. The entire plot was mulched with 7.5-10 cm long pine bark nuggets to a depth of 8 cm (Florida Potting Soil, Orlando, FL) immediately after planting. A second (replicate) plot was planted Nov. 16, 2004 in the same manner and adjacent to the first plot.

Two irrigation frequencies (every 2 or 4 d) and three irrigation volumes (3, 6 or 9 L per plant per irrigation event) were evaluated in 5 blocks, for a total of 30 plants per species for each planting date. The two irrigation frequencies were randomized within each block; species and irrigation volume were randomized within each frequency. Each plant was irrigated with three bubbler emitters (Model Shrubbler® 360°, Antelco®, Longwood, FL) calibrated to deliver the desired volume. Each emitter was mounted 10.2 cm above ground level with one emitter located on the east and west side of each plant, 15 cm from the outside of the rootball, and the third emitter positioned on the rootball. Irrigation was switched on and off using a valve controller (Model SVC, Hunter® Industries Inc., San Marcos, CA). Irrigation began at 0500 HR and was completed by 0600 HR each day. Flow meters (Model C700TP, ABS, Ocala, FL) were installed for each frequency × block combination to record irrigation volume applied. Regular irrigation was discontinued 11 WAP. Supplemental irrigation was supplied when signs of water stress (severe wilting) were apparent and was applied to each shrub consistent with the irrigation frequency and volume treatment that each shrub had received.

Controlled-released fertilizer was applied every 3 months beginning 30 d after transplanting at a standard rate of 0.45 kg N/100 m^2 of 12N-0.9P-11.6K Southern Landscape Fertilizer (LESCO, Inc., Sebring, FL) uniformly broadcast to a 0.84 m^2 area around each plant. Weeds were controlled with periodic hand-pulling and *N*-(phosphonomethyl) glycine (glyphosate). Shrubs were not pruned during the study. Rainfall data was collected with a weather station on site.

To evaluate shrub establishment and growth, canopy height, greatest canopy width (width 1), and width perpendicular to the greatest canopy width (width 2) were measured at planting, and at 26, 34, and 52 WAP. These measurements were used to calculate canopy growth index (GI (m^3) = height × width 1 × width 2). Differences in initial shrub size at planting were accounted for by evaluating canopy growth. Canopy growth was calculated as follows: GI (m^3) - initial GI (m^3). Shrub quality was evaluated based on a visual estimate of plant density and dieback, was rated at 52 WAP on a scale of 1 (dead) to 9 (dense plant, no dieback similar to the indicator plants).

Root spread radius measurements were made at 26, 34, and 52 WAP. Root spread was measured by gently removing the mulch layer from a section of soil approximately 30 cm wide just beyond the estimated edge of the root system on two opposite sides (east and west) of the shrubs from each treatment combination, and gently digging toward the plant until the outermost roots (those farthest from the trunk) were identified. Distance between the trunk and the farthest root was recorded as root spread radius. Mulch was carefully spread back into place. Root spread radius to canopy radius ratio was calculated by dividing root spread radius by the canopy radius. Canopy radius was calculated by dividing average diameter of the canopy by two.

Canopy dry weight and root system dry weight were measured at 64 WAP. The entire above ground canopy was harvested by severing the trunk at ground level. Two 1/8th wedge-shaped sections of the roots extending beyond the trunk were harvested for a total of ¼ of the root system. Substrate and soil were removed from roots. Shoot and root mass were dried at 65˚C until constant dry weight was obtained. Total root system dry weight was calculated by multiplying the harvested weight by four. Root to shoot biomass ratio was calculated by dividing total root system dry weight by canopy dry weight.

Midday shoot water potential (Ψ_w) was measured on two replicates of each treatment combination for all species including the established indicator plants. Shoot water potential was determined with a pressure chamber (Model 3000; Soil Moisture Equipment Corp., Santa Barbara, CA) using compressed N, with pressure increasing at a rate of 2.5 kPa/s^2. Measurements were made on individual stem sections (≈ 10 cm long) at 19 WAP, which was two months after irrigation was discontinued.

Canopy GI, root spread radius, root spread to canopy ratio, shoot dry weight, root dry weight, root dry weight to canopy dry weight ratio, and stem water potential were analyzed separately for each species using the PROC MIXED procedure in SAS (Version 9.1, SAS Institute, Cary, NC). Mean separation was by Tukey's HSD Test ($P < 0.05$).

Due to non-normal distribution, landscape quality ratings were analyzed using the non-parametric procedure outlined in Shah and Madden (2004). Landscape quality ratings were first ranked using the PROC RANK procedure; the ranks were then used in PROC MIXED procedure to calculate ANOVA-type statistic, which was used to test the null hypothesis. Mean separation was by Tukey's HSD Test ($P < 0.05$). Each planting date was analyzed separately.

Results and Discussion

Irrigation frequency and volume had no effect on *P. tobira* 'Variegata' at any time for any measured root or shoot parameter during the study (data not shown). This indicates that these shrubs can be established with 3 L of irrigation applied every 4 d under the conditions of this study. Applying more volume or irrigating more frequently did not increase survival or growth. Irrigation frequency and volume did not affect *I. cornuta* 'Burfordii Nana' and *V. odoratissimum* canopy dry weight, root dry weight, root dry weight to canopy dry weight ratio (May planting: Tables 1 and 2; Nov planting: data not shown), and stem water potential after planting (data not shown). Similarly, Gilman et al. (1998) reported that growth of a drought tolerant tree (*Q. virginiana* Mill.) planted from either containers or a field nursery did not respond to increasing irrigation volume during the months immediately following planting.

V. odoratissimum was the only species where canopy growth was affected by irrigation treatment for plants installed in May 2004. *V. odoratissimum* canopy growth 26 WAP was greater when irrigated every 2 d than every 4 d, but these results did not persist through 34 or 52 WAP (Fig 2A). This indicates that growth response to more frequent irrigation only occurred while plants were irrigated, with no lasting impact on growth once irrigation ceased. Trees also responded to more frequent irrigation during establishment with increased growth, but the difference in size persisted for 5 years (Gilman et al., 2003). *V. odoratissimum* canopy density was slightly, but significantly, reduced when shrubs received 6 L irrigation compared with 3 or 9 L (Table 2). Although *I. cornuta* 'Burfordii Nana' canopy growth was not influenced by irrigation treatment, canopy dieback was significantly reduced when shrubs were irrigated every 2 d compared to every 4 d ($P = 0.04$) (Table 3).

V. odoratissimum and *I. cornuta* 'Burfordii Nana' installed in Nov. 2004 were influenced by irrigation treatment. *I. cornuta* 'Burfordii Nana' canopy growth was greater at 26 WAP when irrigated with 6 L compared with 3 or 9 L every 4 d, but not with every 2 d irrigation ($P = 0.02$) (Fig 2B). There was no impact of irrigation volume or frequency on *I. cornuta* 'Burfordii Nana' canopy growth after 26 WAP. *V. odoratissimum* canopy growth was greater when supplied with 3 L irrigation than 6 or 9 L at 34 WAP ($P = 0.03$) (Fig 2C), but there was no impact of irrigation on *V. odoratissimum* canopy growth after that.

Canopy growth and plant quality results, combined with results of past research, suggest that establishment of these shrub species may be more influenced by environmental conditions such as rainfall than by the irrigation frequency and/or volume. Rainfall was below average for the first 4 WAP in May, during which time plants were being irrigated;

in contrast, rainfall was above average for the remainder of the irrigation period (4-11 WAP) (Fig 3). Above average rainfall continued through 20 WAP (Fig 2), which was 9 weeks after irrigation ceased. Total rainfall the first 6 months after planting was 384 mm (15.12 in.) above normal, which probably negated any irrigation treatment effects. Other research showed reduced effects of irrigation on canopy growth (Stape et al., 2008) or yield (Rzekanowski and Rolbiecki, 2000) in the wetter year of a multiple year study. Following the Nov. planting, rainfall was below average for the 11 weeks, during which time irrigation was supplied; however, rainfall was above average for approximately the next 16 weeks (Fig 3), which may have negated any irrigation treatment effects when shrubs were measured at 26, 34, or 52 WAP. Altogether, an additional 182 mm (7.2 in.) of rainfall occurred above the historical average rainfall during the 16 weeks after irrigation was discontinued. The different volumes and frequencies of irrigation applied to the root ball and to the small area around the root ball did not appear to have greatly influenced canopy growth or health of 11.4 L container-grown shrubs in landscape soil under average or above average rainfall conditions. Irrigating every 4 d with 3 L appears to efficiently establish shrubs of this size when average rainfall occurs after planting.

V. odoratissimum root systems were not influenced by irrigation treatment at any time. Only *I. cornuta* 'Burfordii Nana' root spread and root spread to canopy spread ratio were influenced by irrigation treatment. *I. cornuta* 'Burfordii Nana' root spread radius at 26 and 52 WAP (Fig 4A) and root spread to canopy spread ratio at 52 WAP (Fig 4B) were greater when shrubs received 3 or 9 L irrigation compared to 6 L irrigation in the May planted plot. Root spread radius was not different among main effect treatments for shrubs planted in Nov., but the interaction between irrigation frequency and volume on root spread to canopy spread ratio was significant ($P = 0.04$) (Fig 4). *I. cornuta* 'Burfordii Nana' irrigated every 4 d produced the least root spread to canopy spread ratio when supplied with 9 L compared to 3 L (34, 52 WAP) or 6 L (26 WAP). In agreement with Gilman et al. (1996) this suggests that applying excessive irrigation volume (in this case 9 L) reduced root spread to canopy spread ratio for this drought tolerant species, and could increase the time needed for plants to grow enough roots to survive without irrigation.

Other studies reported reduced root growth with increasing irrigation during establishment. For example, increased irrigation frequency in winter planted *Photinia* x *fraseri* decreased growth; however, neither increased frequency of irrigation (every 3.5 or 7 d) nor increased volume (50, 75, or 100% replacement of actual water use) significantly affected growth of summer installed plants (Welsh et al., 1991). Our study found only slight influences in shrub growth from irrigation frequency and volume regardless of the time of year when data was collected. Although season of planting could not be compared in our study, it seems that under conditions of regular rainfall, *V. odoratissimum*, *P. tobira* 'Variegata', and *I. cornuta* 'Burfordii Nana' shrubs were mostly established by about 19 WAP when 3 L water was supplied every 4 d. This is indicated by the similarity of xylem water potential between test plants of all treatments and established indicator plants (data not shown). However, significant and frequent rainfall occurred during much of the study. When the first prolonged dry period without rainfall for 33 d occurred after irrigation was discontinued on the May planted shrubs, a single irrigation application (Nov. 2004, Fig 3) was needed to reduce water stress as evidenced by wilting leaves or shoots on the shrubs. Indicator plants installed 7 months prior to test plants were not irrigated because they did not exhibit stress symptoms. This would indicate that shrubs were not fully established and therefore were not able to sustain themselves on rainfall alone, even 6 months after planting. It is possible then that during significant periods of dry weather the first year after planting shrubs may require occasional irrigation to maintain a favorable water status.

Irrigation frequency affected shrub growth during establishment when a similar study was conducted on the same three species under a rain shelter (Scheiber et al., 2007). *V. odoratissimum* receiving 3 L irrigation every 7 d had only 50% survival. Additionally, *P. tobira* 'Variegata' and *V. odoratissimum* had greater growth (e.g., leaf area, shoot dry weight, total biomass) when irrigated every 2 d compared with every 4 or 7 d. Since our data showed little difference in plant response between every 2 and 4 d irrigation frequencies in the outdoor environment, rainfall appears very important in helping 11.4 liter container-grown shrubs during the establishment period. However, growth and survival of *I. cornuta* ‘Burfordii Nana’ under a rain shelter were not affected by irrigation frequency indicating very high drought tolerance (Scheiber et al., 2007). Other research under a rain shelter showed that *I. cornuta* ‘Burfordii Nana’ could survive during the establishment period when receiving irrigation once every 14 d for 13 weeks after planting (Gilman et al., 1996). While irrigation did not generally influence growth in our study (under normal or greater rainfall), Scheiber et al. (2007) suggested that more frequent irrigation may be necessary to establish 11.4 L container-grown shrubs under drier conditions.

Research suggests that small container-grown woody plants installed in the landscape do not respond to irrigation with increased growth (Paine et al., 1992). This is because there are many roots on the outside surface of the container root ball compared with the inside of the root ball (Arnold and Struve, 1993); whereas on woody plants in larger containers (Marshall and Gilman, 1998; Stabler and Martin, 2000), there are fewer roots on the outside surface of the root ball compared with the inside. A large percentage of the total plant root area on the outside surface of the root ball may offer small plants the advantage of quicker establishment (Watson, 2005). This might explain why small plants may not respond to irrigation when there is some rainfall in the months after planting to moisten soil surrounding the root ball. The larger plants remain stressed longer because there is a large portion of the root system still present in the original potting substrate even three years after planting (Gilman and Kane, 1991). Gilman et al. (1996) showed that root contact with landscape soil on recently planted containers is vital to managing post-planting stress, and that this contact is attributed to the roots present on the outer periphery of the root ball.

Summary

Irrigation frequency and volume had no effect on *P. tobira* 'Variegata' and minimal effect on *I. cornuta* 'Burfordii Nana' and *V. odoratissimum*. Our results suggest that these shrub species can be established with 3 L of irrigation applied every 4 d under the normal rainfall conditions. Applying greater volumes of irrigation did not increase shrub survival or growth.

Study B. Irrigation frequency and shrub establishment under a rain shelter - Apopka, FL

Materials and Methods

Planting and irrigation treatments.

I. cornuta ‘Burfordii Nana’, *P. tobira* ‘Variegata’, and *V. odorotissimum* obtained from a commercial nursery in 11.4 L containers were planted on Aug. 11, 2004 into an excessively drained fine sand (Apopka fine sand series) under an open-sided clear polyethylene covered rainout shelter 4 m tall. Species were selected to represent taxa with low, medium, and high water requirements, respectively. Classifications were based on plant water use efficiency estimates for containerized specimens grown under nursery production conditions and information garnered from a survey conducted among wholesale nursery growers regarding plant irrigation requirements (Beeson, 2000; Henley et al., 2000). Taxa were planted on 1.8 m centers in 1.5 m wide strips and mulched with 7.5 to 10 cm pine bark nuggets to a depth of 7.5 cm (Sunrise Landscape Supply, Orlando, FL). Areas between strips were covered with a single layer of black polypropylene ground cloth (0.6 m wide; BWI Companies, Apopka, FL) to inhibit weed growth. Before transplant, soil under the shelter was saturated to a depth of 0.6 m. To evaluate the effect of irrigation frequency on establishment rate and growth, each species was irrigated every 2, 4, or 7 d and received 9 L of water per plant per irrigation event. Each plant was irrigated with three bubbler emitters (Model Shrubbler 360; Antelco, Longwood, FL) applying 3 L each. Each emitter was mounted 10.2 cm above ground level with one emitter located on the north and one on the south side of each plant, 15 cm from the outside of the root ball, and the third emitter positioned on the root ball.

Irrigation of each bed was controlled as a separate zone using an automated irrigation time clock (Model Sterling 12; Superior Controls Co., Valencia, CA). Irrigation began at 0500 HR and was completed by 0600 HR each day. Flow meters (Model C700TP; ABS, Ocala, FL) were installed for each zone to record irrigation volumes Monday through Friday. Weekend irrigation volumes were included in total volume recorded the next Monday.

In May, 2004, 6 replicates of each species were planted into a companion open field plot (Apopka fine sand series) to serve as control indicator plants for water potential measurement comparisons. Planting occurred 3 months before installation of rainout shelter plants to permit establishment. Plots were irrigated as previously described. Only one plant per species was used for water potential measurements on each sampling date.

Fertilization of each plot was managed using best management practices (Trenholm et al., 2002). Controlled-release fertilizer was uniformly broadcast in each bed area 30 d after transplanting at a standard rate of 0.91 kg N/100 m^2 of 12N–0.9P–11.6K Southern Landscape Fertilizer (LESCO, Sebring, FL).

Growth indices and biomass. Measurements of average canopy height, widest canopy width (width 1), and width perpendicular to the widest width (width 2) were recorded to calculate growth indices (growth index = height x width 1 x width 2). All plants were measured immediately after planting, monthly, and at final harvest. The experiment ended Feb. 2005 and plants immediately harvested. To calculate canopy dry weight, shoots were severed at the soil line and dried at 65º C until constant dry weight was obtained. To obtain new root dry weight, one-eighth segments of the soil volume outside of the root ball and extending beyond the longest root in each segment were removed from the north northeast (NNE) and south southwest (SSW) sides of each plant. Substrate or soil was removed from roots, and roots were dried as described for shoots. Dry weights of NNE and SSW segments were summed and multiplied by 4 to obtain total new root dry weight. At transplanting, a representative sample of three plant replications per species were measured and dried as described to obtain initial values. Average initial root dry weight in the root ball and total new root dry weight were summed to obtain an estimated total root dry weight for calculation of shoot-to-root biomass ratios. Root lengths were determined by measuring the longest root extending from the center of the root ball in each harvested segment.

Stem water potential and leaf gas exchange measurements. Shoot water potential (Ψw) was measured monthly on all replicates of each species for each treatment beginning 8 WAP. Measurements were made at predawn, midday, and dusk on the day before irrigation (stressed) and the day of irrigation (unstressed). Shoot water potential was determined with a pressure chamber (Model 3000; Soil Moisture Equipment Corp., Santa Barbara, CA) using compressed N with pressure increasing at a rate of 2.5 kPa/s^2. Measurements were made on individual twigs (10 cm long). Cumulative daily water stress integrals (S_Ψ) were calculated as described by Schulze et al. (1980) and Beeson (1992). Area over the water potential curve was integrated and the absolute value taken for each species on each sampling date. G_S measurements were at 1000 HR, 1300 HR, and 1600 HR on the same sampling dates described for shoot water potential. Measurements were taken on two leaves on each plant during each sampling period with a steady state porometer (LI-1600; LI-COR, Lincoln, NE).

Climatic data. Daily climatic data were obtained from the Florida Automated Weather Station (FAWN) located 50 m from the site. Photosynthetic photon flux (PPF) was measured within the rainout shelter with a sunfleck ceptometer (Decagon Devices, Pullman, WA) and a 12% reduction in PPF was noted.

Aesthetic quality. Landscape quality, based on aesthetic appearance, was rated monthly by three subjects on a scale of 1 (dead) to 5 (mounded, proportional form; dense; complete coverage, no dieback). Ratings were averaged across subjects.

Data analysis. The experiment was conducted as a randomized complete block design with four blocks of single plant replicates. Each block contained all three species and all three irrigation frequency combinations for a total of nine plants per block. Data were analyzed separately for all species. Growth data, consisting of final plant height, growth index, shoot dry weight, root dry weight, total biomass, and shoot-to-root ratio, were analyzed as a one-way analysis of variance with three irrigation frequencies and four replications. Root length and root dry weight were analyzed separately by quadrant as a 3 × 2 factorial with three irrigation frequencies and two quadrants. Landscape quality was analyzed using a one-way analysis of variance for each sampling period. Cumulative water stress integral values and g_s were analyzed as repeated measures using a split plot design with irrigation frequency as the main plot and day as a subplot (Snedecor and Cochran, 1980). Each sampling date was analyzed separately. Where significant differences were indicated, mean separation was by Fisher protected least significance differences (Snedecor and Cochran, 1980). All analysis was conducted using SAS (version 8.1; SAS Institute, Cary, N.C.).

Results and Discussion

Growth and biomass. Survival was unaffected by irrigation frequency with the exception of *V. odorotissimum*. By 16 WAP, 50% of *V. odorotissimum* plants irrigated every 7 d were dead. No other plants of any species died.

For *I. cornuta* 'Burfordii Nana', irrigation frequency had no effect on final growth index, height, leaf area, total shoot and root dry weight, new shoot and root dry weight, total biomass, or shoot-to-root biomass ratios. Bryla et al. (2003) reported similar results for *Prunus persica* (L.) Batsch 'Crimson Lady' irrigated at various frequencies with furrow or microjet irrigation. Two- and 4-d irrigation frequencies increased root extensions by 30% and 17%, respectively, relative to plants irrigated every 7 d (Table 10). Root dry weight was greater in the northeast segment (11.3 g) than in the southwest sector (6.8 g). Marshall and Gilman (1998) also found more root growth on the northeast side of red maples after transplant and suggested the response may be the result of shading from the canopy.

For *P. tobira* 'Variegata', final height, total root dry weight, new root dry weight, and shoot-to-root biomass ratios were similar for all irrigation frequencies (data not shown). However, plants irrigated every 2 d had greater leaf area, shoot dry weight, biomass, and final growth index than plants irrigated every 4 or 7 d (Table 11). Growth increased by at least 42% and 52%, dependent on parameter, if plants received irrigation every other day relative to applications every 4 or 7 d, respectively. Root lengths were 36% and 50% greater, respectively, for P. tobira 'Variegata' receiving irrigation every 2 d compared with 4 and 7 d frequencies (Table 10).

For *V. odorotissimum*, irrigation frequency did not affect final height, growth index, or shoot-to-root ratios (data not shown). However, leaf area, shoot dry weight, and total biomass were less for the 7 d frequency compared with the 2 d frequency (Table 11). New root dry weight was 2.3 times and 14.1 times greater for plants irrigated every 2 d compared with plants irrigated every 4 or 7 d, respectively. Similar results were found for total root dry weight with production among 2 d frequency plants increasing by 63% and 147% versus 4 and 7 d frequencies, respectively (Table 10). *V. odorotissimum* irrigated every 2 d increased root lengths by 1.3- and 2.8-fold versus 4 and 7 d treatments, respectively (Table 10). Pour et al. (2005) reported leaf, stem, and root biomass of *Pistasia vera* L. decreased with increasing irrigation intervals. Similar results were reported for *Acer nigrum* Michx., *Acer saccharum* Marsh., and *Coffea arabica* L. (Azevedo et al., 2002; Graves, 1994).

Water potentials. Cumulative water stress (S_Ψ) of *I. cornuta* 'Burfordii Nana' was affected by an irrigation frequency × stress day interaction (Fig. 9) with S_Ψ ranging from 2.4 to 20.4 MPa/h. On the day before irrigation (stressed), S_Ψ (Fig. 9) was greater and predawn Y (data not shown) more negative for plants irrigated every 7 d at 8 and 12 WAP. Plant stress declined (i.e., S_Ψ was less and predawn Ψ became less negative) on the stressed day as irrigation frequency increased. On the day of irrigation (unstressed), plants were less stressed in comparison with the previous stressed day, and there were no differences among irrigation frequencies for all measurement dates. Only plants irrigated every 7 d on the day before irrigation had higher S_Ψ at 16 WAP. There were no differences in S_Ψ by 24 WAP. Similar trends were observed for both midday (Ψ_{midday}) and dusk (Ψ_{dusk}) water potentials (data not shown). Irrigation frequency had no affect on *P. tobira* 'Variegata' water potential, and interactions with stress day were not significant ($P > 0.05$). However, $\Psi_{predawn}$, S_Ψ (Table 12), Ψ_{midday} and Ψ_{dusk} (data not shown) of *P. tobira* 'Variegata' were affected by stress day through 12 WAP.

Water stress was always greater on the day before irrigation than on the day of irrigation. By week 16, $\Psi_{predawn}$, Ψ_{midday}, Ψ_{dusk}, and S_Ψ stress levels were similar among irrigation frequencies. However, at 24 WAP, S_Ψ was again higher on the day before irrigation compared with irrigation day (Table 13). This may be attributed to new shoot growth flushes that likely altered shoot-to-root ratios. Rapid shoot to root balancing is essential to prevent water stress (Beeson, 1992; Gilman et al., 1998; Montague et al., 2000).

Among *V. odorotissimum* plants, $\Psi_{predawn}$ became less negative on irrigation day (unstressed) compared with the day before irrigation (stressed) at 8 and 12 WAP (Table 13). Similar results occurred for S_Ψ at 12 WAP. An irrigation frequency × stress day interaction occurred at 8 WAP with lower S_Ψ on irrigation day (data not shown). Values ranged from 13.3 to 2.6 MPa/h and were lowest among plants irrigated every 2 d on irrigation day. By 16 WAP, treatment, stress day, and irrigation frequency × stress level day effects were nonsignificant ($P > 0.05$) for $\Psi_{predawn}$, Ψ_{midday}, Ψ_{dusk}, and S_Ψ with the exception of a midday stress day effect at 20 WAP (data not shown). When stress day effects were significant, water stress was greater the day before irrigation.

Leaf gas exchange (g_s ***).*** On irrigation day for *I. cornuta* 'Burfordii Nana', g_s increased compared with the day before irrigation at 8 and 12 WAP (Table 12). Irrigation frequency only affected g_s at 12 WAP with greater mean g_s within the 2 d treatment compared with 4 and 7 d treatments. Mean g_s was significantly higher within the 4 d treatment compared with the 7 d treatment. Interactions were not significant and no differences for any parameter were evident by 16 WAP.

Treatment and stress day effects on g_s were found for *P. tobira* 'Variegata' at 8, 12, and 20 WAP (Table 12). Leaf gas exchange was directly proportional to irrigation frequency for all treatments with mean g_s declining from 2 to 7 d. On the day before irrigation (stressed), g_s was less than on irrigation day (nonstressed) at 8 and 20 WAP; however, at

12 WAP, g_s was less on irrigation day. Lower mean g_s values on irrigation day cannot be explained. Correlations between g_s and environmental factors vapor pressure deficit, reference evapotranspiration, daily high temperature, relative humidity, and total daily solar radiation were nonsignificant (data not shown). Despite a treatment × stress day interaction at 16 WAP (Table 12), mean g_s was highest for the 2 d irrigation frequency on the day of irrigation and lowest for the 7 d frequency the day before irrigation with mean g_s ranging from 188.8 to 53.1 mmol/m^2, respectively (data not shown).

V. odorotissimum irrigated every 2 d had higher mean g_s than those irrigated every 4 and 7 d at 8, 12, and 16 WAP (Table 12). No differences in mean g_s were found between 4 and 7 d irrigation frequencies with the exception of 16 WAP. By 20 WAP, irrigation frequency effects were not significant. Throughout the experiment, no effects resulting from stress day were found, and there were no interactions between irrigation frequency and stress day. Similar results have been reported for both herbaceous and woody ornamentals (Chu et al., 1995; Jaimez et al., 1999; Tripepi et al., 1991). Tripepi et al. (1991) found daily irrigation increased g_s among *Betula pendula* Roth seedlings compared with 3 or 5 d irrigation frequencies.

Numerous methods for determining establishment can be found in the literature. Beeson (1994) considered *Q. virginiana* Mill. established when differences between predawn and dusk potentials were within 0.1 MPa on irrigation day. No such trends were identified in the current study. Comparisons of predawn Ψ between transplanted and established controls were used as an establishment measure for *Acer platanoides* L. ‘Schwedleri’ and *Tilia cordata* Mill. ‘Greenspire’ (Montague et al., 2000). Beeson and Gilman (1992) state S_Ψ is a more sensitive measure of diurnal water stress than predawn Ψ and compared S_Ψ between transplanted and established plants of *Q. virginiana* (Beeson, 1994) and *Pinus elliottii* Engelm. (Beeson and Gilman, 1992). However, we found both measures were comparable estimates of shrub establishment. S_Ψ differences between transplanted and established indicator plants were nonsignificant by 20, 16, and 16 WAP, respectively, for *I. cornuta* ‘Burfordii Nana’, *P. tobira* ‘Variegata’, and *V. odorotissimum* (data not shown). Predawn Ψ were similar at 16 WAP for all species (data not shown). In the current study, water potentials between stressed and unstressed plants were also not significant at 16 WAP for all species with the exception of *I. cornuta* ‘Burfordii Nana’ irrigated every 7 d on the day before irrigation (stressed). We found comparisons between stressed (non-irrigated) and unstressed (irrigated) plants is a new method for estimating establishment. This measure of establishment correlated with our estimates of establishment using comparisons of stress between transplanted and established plants, a technique well documented in the literature (Beeson, 1994; Beeson and Gilman, 1992; Montague et al., 2000).

I. cornuta ‘Burfordii Nana’ transplants were established within 16 to 20 WAP whether irrigated every 2 or 4 d. Irrigating shrubs every fourth day instead of every second day resulted in a 100% reduction in irrigation volume applied with equivalent growth. Although establishment was delayed by 1 to 2 months if plants were irrigated every 7 d, growth was not reduced compared with irrigating every 2 or every 4 d.

Similar results were found for *V. odorotissimum* and *P. tobira* ‘Variegata’, except irrigation frequency had no effect on establishment time. Plants were established by 16 WAP, but differences in irrigation volume applied were significant with 2, 4, and 7 d treatments receiving 826.6, 424.7, and 249.3 L, respectively. Unlike *I. cornuta* ‘Burfordii Nana’, growth and aesthetic quality were reduced as the interval between irrigations increased. Our protocol was not designed to determine whether this was incited by irrigation frequency or volume. *V. odorotissimum* irrigated every 2 d had greater root growth (i.e., mass and length) compared with other irrigation frequencies, and shoot growth and aesthetic quality was reduced on plants irrigated every 7 d (Table 14). Furthermore, 50% of *V. odorotissimum* irrigated every 7 d died. Irrigating *P. tobira* ‘Variegata’ every 2 d increased leaf area, shoot dry weight, biomass, growth index, and root length relative to 4 and 7 d treatments. Differences in growth are associated with higher g_s rates for plants irrigated every 2 d. Reductions in g_s in response to water stress have been reported for numerous herbaceous and woody species as an avoidance mechanism to reduce desiccation and conserve water; however, photosynthesis declines and growth is reduced (Clark and Hiler, 1973; Kramer, 1987; Montague et al., 2000; Syros et al., 2004). Reductions in growth in response to declines in g_s have been reported for *A. platanoides* ‘Schwedleri’ and *T. cordata* ‘Greenspire’. Montague et al., (2000) found g_s declined by 1.5 to 13 times for transplanted *A. platanoides* ‘Schwedleri’ trees compared with nontransplanted control trees; values ranged from 1.3 to 19.5 times for *T. cordata* ‘Greenspire’. Consequently, photosynthesis declined during the first growing season and stem area, shoot elongation, leaf size, and total leaf area were significantly reduced among transplanted trees (Montague et al., 2000).

Summary.

Data indicate that for *V. odorotissimum*, *I. cornuta* 'Burfordii Nana' and *P. tobira* ‘Variegata’ an irrigation frequency of every 4 d is sufficient for establishment within 16 WAP. However, growth of *V. odorotissimum* and *P. tobira* ‘Variegata’ can be enhanced by more frequent irrigation. It must be noted the current study was conducted in a rainout structure to simulate maximum stress conditions and effect of rainfall events could decrease establishment times or increase growth rates.

Study C. Phase One - Irrigation frequency and shrub establishment study- Citra, Balm, and Ft. Lauderdale, FL

Materials and Methods

Irrigation frequency treatments. In north and central Florida locations (Citra and Balm, Florida) three shrub species (*I. cornuta* ‘Burfordii Nana’, *P. tobira* ‘Variegata’, and *Viburnum odoratissimum* Ker Gawl) obtained from a commercial nursery in 11.4 liter smooth-sided containers, were planted at two sites in the state of Florida: 1) Plant Science Research and Education Unit located in north Florida (Citra, FL; Arredondo sand, USDA hardiness zone 8b) and 2) Gulf Coast Research and Education Center located in central Florida (Balm, FL; Zolfo fine sand or Seffner fine sand, hardiness zone 9a). Shrubs were planted Sept. 2004 and 2005, Dec. 2004 and 2005, Mar. 2005 and 2006, and June 2005 and 2006, for a total of eight planting dates at 3 month intervals.

Three irrigation frequencies (every 2, 4, or 8 d) were applied at each planting date randomly to six plant replicates at each location. Irrigation was terminated for each planting date, irrigation frequency, and site combination individually once shrub roots grew to the edge of the foliage canopy (within 12 to 22 WAP for all plantings). Previous work suggested that this species could survive at this site with little irrigation once roots reached the edge of the canopy (Gilman et al., 2009).

In the south Florida location (Fort Lauderdale, Florida), *Psychotria nervosa* Swartz , *Acalypha wilkesiana* Müll. Arg., *Murraya paniculata* 'Lakeview' (L.) Jack and *Viburnum odoratissimum* Ker Gawl obtained from a commercial nursery in 11.4 L (# 3) smooth sided pots, were planted at the University of Florida, Fort Lauderdale Research and Education Center located in south Florida (Fort Lauderdale, FL; Margate fine sand, USDA hardiness zone 10b). *P. nervosa*, *M. paniculata* 'Lakeview' and *V. odoratissimum* shrubs were planted in Sept. 2004, Dec. 2004, Mar. 2005, and June 2005 and irrigated every 2, 4, or 8 d. *A. wilkesiana*, *M. paniculata* 'Lakeview' and *V. odoratissimum* shrubs were planted in Sept. 2005, Dec. 2005, Mar. 2006, and June 2006 and irrigated every 1, 2 or 4 d. Six replicates of *P. nervosa*, *A. wilkesiana*, and *M. paniculata* 'Lakeview' shrubs were planted for each irrigation frequency (3) and planting date (4) combination. Irrigation for both experiments was terminated approximately 28 weeks after planting (WAP) based on previous research.

P. nervosa is best grown as an understory plant in partial to full shade (Broschat and Meerow, 1996; Gilman, 1996). When *P. nervosa* plants are grown in full sun they require a lot of water (Gilman, 1996). Because of poor performance (plant quality ratings ranging from 4 to 5) under full sun conditions, *P. nervosa* was replaced in the second experiment with *A. wilkesiana*.

Planting and irrigation methods. For all three sites, shrubs were planted on 3.6 m centers at grade and root balls were left undisturbed at planting. Shrubs were mulched and irrigation was installed as described in study "A". Irrigation frequency was controlled using separate zones and an automated irrigation time clock (Model Sterling 12, Superior Controls Co., Inc., Valencia, CA) in central and south Florida or a valve controller (Model SVC, Hunter® Industries Inc., San Marcos, CA) in north Florida. Irrigation in zones north and south Florida began at 0800 HR and was completed by 0830 HR; irrigation in central Florida began at 0200 HR and was completed by 0230 HR. Irrigation was terminated for each planting date, irrigation frequency, and site combination individually once shrub roots grew to the edge of the foliage canopy (within 12 to 22 WAP for all plantings). Previous work suggested that these three shrub species could survive at their sites with little irrigation once roots reached the edge of the canopy (Gilman et al., 2009). Shrub plots were maintained as in study "A".

Cumulative monthly rainfall data was collected at each planting location from Florida Automated Weather Network (FAWN) stations located within 50 m of the planting sites (Figure 1). Historical monthly rainfall volumes were collected from the National Oceanic and Atmospheric Administration (National Oceanic and Atmospheric Administration, 2002). After automated irrigation was terminated, supplemental irrigation (3 L per plant) was supplied periodically to all shrubs for that planting date over the two year post-planting period, only when signs of water stress (severe wilting) were apparent and rainfall was less than 6 mm in any 24 hr period consecutively for 32 d (Figure 1).

Plant survival and quality. Quality (plant density and dieback) was visually rated on a scale of 1 (dead plant) to 9 (dense, full canopy with no dieback) at 28, 52, and 104 WAP. Additionally, plant survival was documented at 28, 52, and 104 WAP for *V. odoratissimum*, *I. cornuta* 'Burfordii Nana', and *P. tobira* 'Variegata'.

Growth index. Growth index (GI) was used as a quantitative indicator of plant growth as in Study "A" on three plant replicates per treatment. GI was recorded at 0 (date of planting), 28, 52, and 104 WAP for *V. odoratissimum*, *P. nervosa*, *M. paniculata* 'Lakeview', and *A. wilkesiana* and at 0, 4, 8, 12, 20, 28, 52, 64, 76, 88, and 104 WAP for *I. cornuta* 'Burfordii Nana' and *P. tobira* 'Variegata'.

Root spread and root to canopy spread ratio. Root spread was measured on three plant replicates per irrigation frequency as in study "A". Root spread radius root spread to canopy spread ratio were calculated as in study "A". Root spread was measured on *V. odoratissimum*, *P. nervosa*, *M. paniculata* 'Lakeview', and *A. wilkesiana* at 28, 52, and 104 WAP and on *I. cornuta* 'Burfordii Nana' and *P. tobira* 'Variegata' at 12, 20, 28, 52, 64, 76, 88, and 104 WAP.

Dry biomass. The entire above ground canopy (shoots) was harvested from three plant replicates per irrigation treatment per planting date at 52 and 104 WAP. Two wedge-shaped sections of soil containing approximately ⅛ (zones 8b and 10b) or ¼ (zone 9a) of the soil volume containing roots (extending beyond the trunk) were excavated from northeast and southwest sides of the same shrubs where the canopy was harvested. Canopy and root biomass were processed to remove soil and dried as in study "A". Total canopy biomass, root biomass, and canopy to root biomass ratio was then calculated as in study "A".

Experimental design and data analysis. The experiment was designed as a randomized complete block design with 3 irrigation frequencies applied randomly to 6 plant replicates within each block (planting date). The field location for each of the eight planting dates was assigned randomly at each location. Canopy GI, root to canopy spread ratio and average root spread were analyzed using the PROC MIXED procedure in SAS (SAS Institute, 2003) with WAP as a repeated measure (*V. odoratissimum*, *P. nervosa*, *M. paniculata* 'Lakeview', and *A. wilkesiana*) or were analyzed separately for each location by WAP (*I. cornuta* 'Burfordii Nana' and *P. tobira* 'Variegata'). For analysis of GI, initial GI (0 WAP) was included in the model as a covariate to account for variation in initial plant size at different planting dates. Quality, survival and harvest biomass data were analyzed separately for each location at 28, 52, and 104 WAP (as applicable). Harvest biomass (biomass ratio, shoot biomass and root biomass) was analyzed using the PROC MIXED procedure in SAS (SAS Institute, 2003). Plant quality and density data were analyzed using the PROC GLIMMIX program in SAS (SAS Institute, 2003) using the multinomial distribution and the cumulative logit link function. Plant survival was analyzed using the PROC GLIMMIX program in SAS (SAS Institute, 2003) using the binomial distribution and the logit link function. Dead plants were treated as missing data. All pair-wise comparisons were completed using the Tukey test with a significance level of $\alpha = 0.05$.

Results and Discussion

Plant survival. Irrigation frequency during establishment had no significant effect on survival of field planted *V. odoratissimum* at any location (data not shown). However, in south Florida, 25% of the *V. odoratissimum* planted between Sept. 2004 and June 2005 that were irrigated every 8 d were dead by 52 WAP, compared with 0 and 8.3% of the plants irrigated every 2 and 4 d (respectively). These results were similar to those reported by Scheiber et al. (2007), where more than half the *V. odoratissimum* irrigated every 7 d under a rainout shelter had died by 16 WAP. Therefore, the 8 d irrigation treatment was removed from the study in south Florida, because although survival was not statistically significant, the 8d treatment resulted in too many dead plants to be practical for most landscape applications.

Irrigation frequency had no effect on survival of *I. cornuta* ‘Burfordii Nana’ or *P. tobira* ‘Variegata’ in north or central Florida or on *P. nervosa, M. paniculata* 'Lakeview', or *A. wilkesiana* shrubs in south Florida (data not shown). Rainfall may have negated any irrigation treatment effects on shrub survival (Figure 1A, B and C). Scheiber et al. (2008) also reported that multiple shrub species, including *P. tobira* ‘Variegata’, *I. glabra* (L.) A. Gray, and *I. vomitoria* Sol. Ex Aiton 'Nana', survived under normal rainfall conditions in Florida after receiving regular irrigation for only 11 weeks.

Plant quality. Irrigation frequency also had no significant effect on quality of *V. odoratissimum* (all locations), *I. cornuta* ‘Burfordii Nana’, *P. tobira* ‘Variegata’ (north and central Florida), *P. nervosa, M. paniculata* 'Lakeview' or *A. wilkesiana* (south Florida) at 28, 52, or 104 WAP (data not shown), despite seasonal differences in the cumulative amount of rainfall that occurred following planting (Figure 1A, B, and C). Results of *V. odoratissimum* differ from and results of *I. cornuta* ‘Burfordii Nana’ concur with those of Scheiber et al. (2007). Scheiber et al. (2007) reported that the aesthetic quality of *V. odoratissimum* was reduced when irrigated every 7 d when compared to plants watered every 2 or 4 d, but aesthetic quality of *I. cornuta* ‘Burfordii Nana’ did not show treatment differences when planted under a rainout shelter in central, FL. However, it is likely that the differences between our findings those of Scheiber et al. (2007) for *V. odoratissimum* may be due to the influence of rainfall. The study by Scheiber et al. (2007) was conducted under a rainout shelter, thereby eliminating the effect of rainfall events, while the plants in our study, received irrigation as a supplement to natural rainfall events (Figure 1A, B, and C). Similarly, Fitzpatrick and Burch (1986) attributed the lack of irrigation effect (0, 1, or 3 times per week) on quality of *Murraya paniculata* L. Jack after 2 months in the field in south Florida to the influence of rainfall events. Paine et al. (1992) also reported no significant effect of irrigation frequency (irrigated every 1, 3, 5 or 7 d) on visual appearance (aesthetics) of *Ceanothus griseus* var. *horizontalis* (Trel.) McMinn, *Rhamnus californica* (Eschsch.) A. Gray, and *Photinia fraseri* Dress when plants received the same total volume of irrigation.

Growth index. Irrigating *V. odoratissimum* every 2 d in north Florida resulted in larger plants at 28 and 104 WAP than irrigating every 4 or 8 d (Table 4). Additionally, *I. cornuta* ‘Burfordii Nana’ planted in north Florida and irrigated every 2 d had greater GI than shrubs irrigated every 8 d (52 and 88 WAP) or every 4 or 8 d (64 and 76 WAP) (Figure 6A). Growth index was also greater for *P. tobira* ‘Variegata’ planted in north Florida and irrigated every 2 d when compared with shrubs irrigated every 8 d from 12 to 104 WAP (Figure 6B). These results are supported by the findings of Scheiber et al.(2007), who reported that *V. odoratissimum* plants grown in a rainout shelter in Apopka, FL and irrigated every 2 d were larger than plants irrigated every 4 or 7 d with 9 L of water per irrigation event. Scheiber et al. (2007) also reported an increase in canopy growth index for *P. tobira* ‘Variegata’ plants irrigated every 2 d under a rainout shelter compared with plants irrigated every 4 or 7 d.

In central Florida, *V. odoratissimum* irrigated every 2 d were significantly larger than those irrigated every 8 d; however, there was no difference in GI for plants irrigated every 2 and 4 d (Table 4). In addition, irrigation frequency had no effect on the GI of *I. cornuta* ‘Burfordii Nana’ or *P. tobira* ‘Variegata’ (data not shown).

Similarly, there were no differences in GI at 28, 52, or 104 WAP in south Florida when *V. odoratissimum* was irrigated using the 2 and 4 d frequencies (Table 4) *P. nervosa* and *M. paniculata* 'Lakeview' shrubs irrigated every 2 d in south Florida had a larger GI at 28 WAP in year one when compared with plants irrigated every 8d; but, there were no differences in GI of *P. nervosa* or *M. paniculata* 'Lakeview' at 52 or 104 WAP. Growth index was not different in year two for *M. paniculata* 'Lakeview' or *A. wilkesiana* shrubs when irrigated every 1, 2, or 4 d (data not shown). It appears that irrigation and rainfall during the first 28 WAP were sufficient to avoid water stress and reduced shoot growth in south Florida, when shrubs were irrigated at least every 4 d. These results differed from those reported by Scheiber et al. (2007), probably due to the influence of rainfall events in our study or climatic differences (Figure 1A, B, C).

Other studies also confirm that increasing irrigation of woody plants in the landscape results in greater growth (e.g. trunk diameter, crown spread, height, etc.) (Gilman et al., 1998; Marshall and Gilman, 1998; Paine et al., 1992; Stabler and Martin, 2000). Paine et al. (1992) reported no significant differences in growth of *Ceanothus griseus* var. *horizontalis*, *Rhamnus californica*, and *Photinia x fraseri* due to irrigation frequency (every 1, 3, 5 or 7d). However, all plants studied by Paine et al. (1992) received the same total volume of water (522 L or 63.8% ET_o) over the 14 week period regardless of irrigation frequency, while the plants in our study (and the other studies that support our findings) received less water when irrigation frequency was reduced.

Root spread. Applying irrigation to the root ball and a small area around the root ball did not restrict roots to this volume of soil; roots of all shrub species grew freely into soil outside this area. Irrigation frequency did not affect the root spread radius of *V. odoratissimum* planted in north or central Florida (zones 8b or 9a) (Table 5). However, roots spread farther from the base of the shrub by 52 WAP when plants grown in south

Florida (zone 10b) were irrigated every 2 d compared with those irrigated every 4 d (Table 5). Barnett (1986) also reported that roots of frequently irrigated (frequent irrigation schedule: daily [0-4 WAP], every 5 d [5-11 WAP], and every 6 d [11-21 WAP]) *Ligustrum vulgare* 'Lodense' extended an average of 45 cm from the plant crown by 21 WAP compared with only 30 cm for plants irrigated less frequently (infrequent irrigation schedule: daily [0-4 WAP], every 10 d [5-11 WAP], and every 12 d [11-21 WAP]). Roots of shrubs (Barnett, 1986) and trees (Marshall and Gilman, 1998) growing in moist temperate climates spread far beyond the area of the soil that was moistened during the irrigation events, indicating that wetting the root ball and the soil immediately around the root ball provides the plants with the capacity to explore a large volume of soil beyond the wetted zone.

In north Florida the roots of *I. cornuta* 'Burfordii Nana' irrigated every 2 d extended further from the trunk base than shrubs irrigated every 8 d at 20, 28, 52, 64, and 88 WAP (Figure 7A). Root spread of *I. cornuta* 'Burfordii Nana' irrigated every 2 d were significantly greater than for shrubs irrigated every 4 d at 28 and 64 WAP only (Figure 7A). Comparable results were noted for *P. tobira* 'Variegata', where root spread was greater for shrubs irrigated every 2 d compared with plants irrigated every 8 d at 20, 28, 64, 76, and 88 WAP (Figure 7B). In the case of *P. tobira* 'Variegata', the 2 d frequency produced greater root spread than plants irrigated every 4 d at 64 WAP only (Figure 7B). Other studies have reported an increase in root growth when irrigation frequency increased (Harris and Gilman, 1993; Marshall and Gilman, 1998). Frequently irrigated (irrigated daily from 2 to 9 WAP then every 2 d from 9 to 24 WAP) red maples had a greater number of roots than the infrequently irrigated treatments (weekly from 2 to 3 WAP, every 3 d from 4 to 9 WAP, and every 10 d from 10 to 19 WAP) at 24 WAP (Marshall and Gilman, 1998) and 5 years (Gilman et al., 2003) after planting. This further supports the idea that irrigation frequency during establishment may continue to influence root growth long after plants are established. Irrigation treatment effects on root extension for shrubs planted in north Florida were significant through 88 WAP, long after the plants were considered established.

In contrast, irrigation frequency did not influence root spread of *I. cornuta* 'Burfordii Nana' and *P. tobira* 'Variegata' when planted in central Florida. Near-normal (historical mean) rainfall that occurred in the central Florida location during most of the study period may have masked the influence of irrigation frequency (Figure 1B). The data suggest that irrigation may not need to be applied more that once every 8d when near normal rainfall occurs after planting. The longest drought in the central Florida location occurred from Feb. 2006-Jun. 2006 and differed from the historical average for that location by only 159 mm compared with a reduced cumulative rainfall of 351 mm in the north Florida location during that same period (Figures 1A, B).

Shoot biomass. Irrigation frequency did not affect dry shoot biomass for *V. odoratissimum* planted in central Florida (Table 7). In north Florida, plants irrigated every 2 d produced significant more dry shoot biomass at 52 and 104 WAP compared to plants irrigated every 4 and 8 d (Table 7). There was also a significant irrigation frequency effect on shoot biomass for shrubs grown in south Florida, where plants irrigated every 2 d produced more shoot biomass than plants irrigated every 4 d by 52 WAP (Table 6). Pour et al. (2005) also reported up to a 50% to 68% increase in stem and leaf dry biomass for *Pistacia vera* L. when irrigation was applied daily compared to every 3 or 7 d, respectively.

Irrigation frequency had no significant effect on the canopy dry weight of *I. cornuta* 'Burfordii Nana' or *P. tobira* 'Variegata' at 52 or 104 WAP when planted in central Florida (Table 8, 9). In north Florida, *I. cornuta* 'Burfordii Nana' irrigated every 2 d had greater canopy dry weight than shrubs irrigated every 4 or 8 d at 52 and 104 WAP, while *P. tobira* 'Variegata' had greater canopy dry weight than shrubs irrigated every 8 d at 52 WAP and every 4 and 8 d at 104 WAP (Table 8, 9). Comparable results were reported by Scheiber et al. (2007), where shoot dry weight was larger for *P. tobira* 'Variegata'. and *V. odorotissimum* irrigated every 2 d compared with plants irrigated every 4 or 7 d. Other studies also found that canopy dry weight increased with increasing irrigation frequency (Knox and Zimet, 1988; Marshall and Gilman, 1998; Stabler and Martin, 2000).

Although, there were no differences in *P. nervosa* or *M. paniculata* 'Lakeview' GI at 52 or 104 WAP, shoot dry weight at 52 WAP was greater for *P. nervosa* and *M. paniculata* 'Lakeview' irrigated every 2 d than every 8 d (Table 6). However, there were no differences between shoot dry weight of *M. paniculata* 'Lakeview' or *A. wilkesiana* when irrigated every 1, 2, or 4 d. We suspect that irrigation frequency during the first 28 WAP had a carry-over effect on shoot dry weight at 52 WAP. Gilman et al. (1998) reported a similar carry-over effect in the second year of production observing that trees grew faster when irrigated frequently for the first 41 WAP than when irrigated infrequently for the first 26 WAP.

Root biomass. Irrigation frequency did not affect dry root biomass of *I. cornuta* 'Burfordii Nana', *P. tobira* 'Variegata', or *V. odoratissimum* at 52 or 104 WAP when planted in north or central Florida (Table 7, 8, 9) or *P. nervosa*, *M. paniculata* 'Lakeview', and *A. wilkesiana* when planted in south Florida (Table 6) similar to Gilman et al. (1996). However, in south Florida, irrigation applied every 2 d to *V. odoratissimum* resulted in significantly more root biomass at 52 and 104 WAP than from plants irrigated every 4 d (Table 7). Similarly, Marshall and Gilman (1998) reported that frequently irrigated (frequent irrigation schedule: 38 L of water daily [2-9 WAP], and every 2 d [10-24 WAP]) *Acer rubrum* L. trees had more new root biomass 5 months after transplant than infrequently irrigated trees (infrequent irrigation schedule: 38 L of water every 7 d [2-3 WAP], every 3 d [4-9 WAP], every 10 d [10-19 WAP], and no irrigation [20-24 WAP]). Similar results were also reported for *Pistacia vera* L. (Pour et al., 2005), *Acer nigrum* Michx., and *Acer sacccharum* Marsh. (Graves, 1994).

Root to canopy ratio. Irrigation frequency had no significant effect on root to canopy spread ratio of *I. cornuta* 'Burfordii Nana', *P. tobira* 'Variegata' , or *V. odoratissimum* planted in north or central (data not shown) or on *P. nervosa*, *M.paniculata* 'Lakeview' (Table 6), or *A. wilkesiana* planted in south Florida. In south Florida, *V. odoratissimum* irrigated every 4 d had a larger root to canopy spread ratio by 28 WAP compared with plants irrigated every 2 d, indicating a period of active root growth and decreased shoot growth (Table 5). By 52 WAP, this trend was reversed (and it held through 104 WAP), where plants watered every 2 d had a higher root to canopy spread ratio than those irrigated every 4 or 8 d (Table 5).

A root extension to canopy spread ratio of approximately 1.0 indicates that the roots have grown to the edge of the shoot canopy and that the root system is sufficiently developed to compensate for daily water losses from the canopy under normal rainfall conditions. By 28 WAP, *V. odoratissimum* planted in north, central, and south Florida had a root to shoot spread ratio greater than 1.0 (Table 5). Studies have suggested that trees are fully established once the root to canopy spread ratio reaches a value between 1.7 and 3 (Gilman, 1998). Four cultivars of *Juniperus chinensis* L. reached a mean root to canopy spread ratio of 2.75 three years after planting; ratios varied from approximately 1.0 to 4.3 depending on the shape of the canopy (Gilman and Kane, 1991). Juniper cultivars with a wide spreading canopy form ('Pfitzeriana' and 'Hetzii') had a lower root to canopy ratio (root to canopy spread ratio approximately 1.0 to 2.2) compared with cultivars with a more upright canopy (root to canopy spread ratio approximately 2.0 to 4.3). Therefore, our *V. odoratissimum* shrubs, which have a wide spreading canopy, may have been nearly established by 28 WAP. Establishment at 28 WAP is further supported by continued root and shoot growth without a decline in quality through 104 WAP when receiving only limited supplemental irrigation (5, 4, and 2 times in north, central, and south Florida, respectively) (Figure 1A, B, and C). During the course of the study, supplemental irrigation (3 L per plant) was applied by hand when signs of water stress (e.g., severe wilting) were apparent and rainfall was less than 6 mm (0.25 in.) in any 24 hr period consecutively for 32 d (Figure 1A, B, and C). Gilman et al. (2009) reported that shrubs planted in the landscape from 11.4 L containers began declining (following the cessation of regular irrigation at 11 WAP) when rainfall was absent for 35 d.

The root spread to canopy spread ratio of *I. cornuta* 'Burfordii Nana' or *P. tobira* 'Variegata' shrubs exceeded a value of 1.0 by 28 WAP, at which time regular irrigation had been discontinued. This indicates that the roots had grown to the edge of the shoot canopy and that the root system was sufficiently established to compensate for daily water loss under the near normal rainfall conditions of this study (Figure 1A and B). Root spread to canopy spread ratio of both species in north and central Florida at 52 WAP was similar to other well established shrub species measured three years after planting from 11.4 L containers (Gilman and Kane, 1991). A stable root to shoot ratio suggests that shrubs have established the natural relationship between root and shoot growth for that species. Gilman and Beeson (1996) reported a similar response of 5 cm caliper *Quercus laurifolia* Michx. planted from fabric containers or field grown. Root pruned trees regenerated sufficient roots to fill the same soil volume with roots one year after transplanting as before transplanting (Gilman and Beeson, 1996).

In south Florida, *P. nervosa* had a root spread to canopy spread ratio of 1.0 at approximately 104 WAP, while *M. paniculata* 'Lakeview' reached a ratio of 1.0 by 52 WAP (data not shown). *A. wilkesiana* plants reached a root spread to canopy spread ratio of 1.0 by 28 WAP, while *M. paniculata* 'Lakeview' shrubs had a ratio of 1.0 by 52 WAP. As such, we speculate that once the root to shoot balance was restored for *P. nervosa* and *M. paniculata* 'Lakeview', shoot growth increased resulting in no difference in shoot dry weight or GI at 104 WAP (Table 6). Several reports confirm that smaller field grown trees as well as container grown trees will establish quicker in the landscape than larger trees because roots come into balance with shoots sooner (Watson, 1985; Beeson and Gilman, 1992; Gilman and Beeson, 1996).

Summary

Under normal rainfall conditions, an irrigation frequency of every 4 to 8 d was sufficient to establish 11.4 L container grown shrubs in north and central Florida, although growth may increase with more frequent irrigation for some species. More frequent irrigation, every 2 to 4 d was most effective for establishing 11.4 L shrubs in south Florida. Shrubs reached a root spread to canopy spread ratio of 1.0 between 12 and 104 WAP, and were therefore considered nearly established by that time. Supplemental irrigation was needed during extended periods of dry weather after regular irrigation was discontinued.

Study D. Phase Two - Irrigation frequency and shrub establishment study using 6 native and 6 non-native shrub species - Citra, Balm, and Ft. Lauderdale, FL

Materials and Methods

Twelve shrub species (Table 1) (6 native to Florida and 6 non-native) obtained from a commercial nursery in 11.4 L *(*# 3) containers, were planted at the Plant Science Research and Education Unit located in north Florida, the Gulf Coast Research and Education Center located in west central Florida, and Fort Lauderdale Research and Education Center located in southeast Florida. Sites and soil conditions were as in phase one.

Shrubs were planted in Dec. 2006 and June 2007 at the Plant Science Research and Education Unit located in north Florida, the Gulf Coast Research and Education Center located in central Florida, and Fort Lauderdale Research and Education Center located in south Florida. Due to irrigation malfunctions in the Dec. 2006 installation at the Gulf Coast Research and Education Center located in central Florida, an additional plot was installed at that location in Dec. 2007. Shrubs were installed and maintained using procedures described in phase one.

Shrubs at the Balm and Citra sites were irrigated with 3 L every 4 d. Shrubs at the Fort Lauderdale site were irrigated with 3 L every 2 d. Six replicates were evaluated for each planting season. Emitters and irrigation application system were installed as in phase one. Irrigations began at 0800 HR and were completed by 0830 HR. Flow meters (Model C700, AMCO, Ocala, FL) were installed for each irrigation treatment to confirm water volume being applied to each row. Irrigation was discontinued at 20 WAP. Data collected (canopy height, canopy width, density, dieback, root spread radius, canopy dry weight, and root dry weight) were measured as in phase one. Canopy data was collected at 0, 4, 8, 12, 20, 28, and 52 WAP. Root spread radius was collected at 12, 20, 28, and 52 WAP. Canopy and root dry weights were collected at 52 WAP.

The experiment was designed as a randomized complete block design with 1 irrigation frequency applied to 6 replicates of 12 shrub species (6 Florida native species and 6 non-native species) within each planting date (planting date = block). Planting date and native nested within species were included in the model as random effects. The field position for the two planting dates was assigned randomly at each location. Data was analyzed separately for each location in Florida. Plant quality data were analyzed at 20, 28, and 52 WAP using the PROC GLIMMIX program in SAS (SAS Institute, 2003) using the multinomial distribution and the cumulative logit link function. Shrub growth index, root spread, and root to canopy spread ratio were analyzed using the PROC GLIMMIX procedure in SAS (SAS Institute, 2003) using the gamma distribution and the log link function. Harvest biomass data for central and south Florida were also analyzed using the PROC GLIMMIX procedure in SAS (SAS Institute, 2003) using the gamma distribution and the log link function. However, harvest biomass data for north Florida were analyzed using the PROC MIXED procedure. For analysis of GI, log of the initial GI (0 WAP) was included in the model as a covariate to account for variation in initial plant size at different planting dates. All pair-wise comparisons were completed using the Tukey test with a significance level of $\alpha = 0.05$.

Results and Discussion

Growth and quality. There were no differences in growth of shoots and roots, or aesthetic quality of native versus non-native shrubs at any of the planting locations. This was consistent with the results from Phase one, suggesting that shrubs planted in north and central Florida could be established from 11.4 L containers with an irrigation regimen of 3 L applied every 4 or 8 d for 20 WAP. In south Florida, shrubs could be established with 3 L irrigation every 2 d for 20 WAP when rainfall conditions were normal or above average. Our results are similar to those of Scheiber et al. (2008), who found that neither native species, nor non-native species were as a group more responsive to irrigation. Growth of 2 of 10 natives and 2 of 10 non-natives increased when irrigated (daily for 17 d, then every 2 d for 7 weeks, then every 7 d) (Scheiber et al., 2008). Enhanced growth of irrigated shrubs seemed to be associated with species habitat preference, since all species that increased in growth as a response to irrigation were native to wet habitats (Scheiber et al., 2008). Additionally, Scheiber et al. (2008) found no differences in aesthetic quality between irrigated and non-irrigated natives and non-native species under normal or greater rainfall conditions

Root spread to canopy spread ratio. There were no differences in the root spread to canopy spread ratio of native and non-native shrubs. Both native and non-native shrubs approached a root spread to canopy spread ratio of 1.0 by 28 WAP and had exceeded 1.0 by 52 WAP. Shrubs in north and south Florida had reached a ratio of 1.0 by 20 WAP. These results differ from those in Phase one, where different shrub species were planted. During phase one, *V. odoratissimum* reached a root to shoot ratio of 1.0 by 28 WAP in all three planting locations; *I. cornuta* 'Burfordii Nana' and *P. tobira* 'Variegata' reached a root to shoot ratio of 1.0 by 28 WAP in north and central Florida; *P. nervosa*, *M. paniculata* 'Lakeview', and *A. wilkesiana* in south Florida reached a root to shoot ratio of 1.0 by 104, 52, and 28 WAP respectively. Root spread to canopy spread ratio of tree species has been reported to be species dependent (Rogers, 1933; Rogers and Vyvyan, 1934; Gilman and Kane, 1991; Kummerow et al., 1977), but roots generally extended 2 to3 times the distance from trunk to dripline on established nursery grown trees (Rogers, 1933; Rogers and Vyvyan, 1934) and 1.7 to 3.7 times the dripline for shrubs (Gilman and Kane, 1991). Shrubs may be considered fully established when the root spread to canopy spread ratio is stable (Gilman and Kane, 1991). Root spread to canopy spread ratio continued to increase throughout the 52 week period of study in phase two, which suggests that shrubs may be nearly established at 52 WAP and able to compensate for evapotranspiration losses without additional irrigation under normal or greater rainfall conditions. Shrubs, native or non-native should be monitored for symptoms of drought stress for 2 years after planting.

Summary

An irrigation frequency of every 4 d in north and central Florida and every 2 d in south Florida with a water volume of 3 L was sufficient to establish native and non-native shrubs from 11.4L containers in the landscape under normal rainfall conditions. There were no differences in growth parameters (e.g., growth index, root spread, root spread to shoot ratio, dry weight) between native and non-native species as a group. Shrubs were established as defined by a root spread to canopy spread ratio of 1.0 between 28 and 104.

Study E. Irrigation frequency and volume study - Apopka, FL

Materials and Methods

V. odoratissimum and *I. cornuta* 'Burfordii Nana' were planted in two separate experimental plots (high water field plot, low water field plot) in Apopka in December 2005, June 2006, December 2006 and September 2007. Plants in the high water field plot were irrigated at one of the following frequencies: daily, every 2 d, or every 4 d with 9 L irrigation per plant per event. Low water field plot plants were irrigated every 2, 4 or 8 d with 3 L per plant at each application. Planting dates, species, and application rates were analyzed separately.

Results and Discussion

Growth index was similar among treatments for both *V. odoratissimum* and *I. cornuta* 'Burfordii Nana' planted in the high water plot in Dec. 2005. Similar results were found for *I. cornuta* 'Burfordii Nana' planted in the low water plot. Irrigation frequency did affect GI for *V. odoratissimum* receiving 3 L of irrigation per event; as frequency decreased, GI decreased. *V. odoratissimum* irrigated every 2 d had a mean growth index of 0.26 m^3 compared to *V. odoratissimum* irrigated every 8 d, which had a mean growth index of 0.15 m^3. Both plots received an additional 170.43 mm (6.71 in.) of rainfall.

For the June 2006 high water field plot planting, only growth index of *V. odoratissimum* was affected by irrigation frequency. Daily irrigation resulted in a significantly higher GI (0.65 m^3) compared to irrigating every 2 d (0.44 m^3) or every 4 d (0.31 m^3). Shoot dry weight, root dry weight, and shoot to root biomass ratio were similar among treatments for *V. odoratissimum* and *I. cornuta* 'Burfordii Nana'. Growth index was also similar among irrigation frequencies for *I. cornuta* 'Burfordii Nana'. In the low water field plot, only growth index was not affected by irrigation frequency. Shoot dry weight, root dry weight, and shoot to root dry weight ratio were significantly lower for *V. odoratissimum* irrigated every 8 d (Table 15). Plants irrigated daily had significantly greater shoot dry weight and shoot to root dry weight ratios compared to other treatments. Results were similar for *I. cornuta* 'Burfordii Nana' except for root dry weight where no differences were found among treatments. Both plots received an additional 592.58 mm (23.33 in.) of rainfall.

With the exception of *V. odoratissimum* root dry weight, all growth parameters (e.g., growth index, shoot dry weight, root dry weight, shoot to root dry weight ratio, root extensions, canopy spread and root extension to canopy spread ratio) were similar among treatments for both species in the low water field plot planted in Dec. 2006. *V. odoratissimum* irrigated every 2 d had greater root dry weight (171.5 g) than plants irrigated every 4 d (156.1 g) or every 8 d (156.1 g). Similar results were found for *I. cornuta* 'Burfordii Nana' planted in the high water field plot. However, irrigation frequencies did affect growth indices, shoot dry weight, shoot to root dry weight ratios, and canopy spread of *V. odoratissimum*. Growth index, shoot dry weight, and shoot to root dry weight ratios were similar between plants irrigated daily and every 2 d, but significantly lower for plants receiving irrigation every 4 d (Table 16). Canopy spread was significantly greater for plants irrigated daily compared to plants irrigated every 4 d. Plants irrigated every 2 d had similar canopy sizes to other irrigation treatments (Table 16). Both plots received an additional 450.09 mm (17.72 in.) of rainfall.

For the final planting date Sept. 2007, growth index, shoot dry weight, root dry weight, shoot to root dry weight ratio, root extensions, canopy spread and root extension to canopy spread ratio of *V. odoratissimum* were similar among irrigation treatments. The shoot to root dry weight ratio of *I. cornuta* 'Burfordii Nana' irrigated every 2 d was greater than other treatments. The higher ratio can be explained by greater shoot growth and less root growth within the 2 d treatment though differences in shoot dry weight and root dry weight were not significant among treatments. Less root growth was also observed for *I. cornuta* 'Burfordii Nana' grown in the low water field plot. Results were similar to those observed for the high water field plot for *V. odoratissimum*. There were no differences in growth parameters among irrigation frequencies (data not shown). The only differences among treatments for *V. odoratissimum* in the low water field plot were found in root extension to canopy spread ratio at 12 WAP and shoot dry weight. Ratios were highest for plants irrigated every 2 d (0.75) and lowest for plant irrigated every 4 d (0.24). Results were intermediate for plants irrigated every 8 d (0.51). Differences in root to canopy spread ratio were no longer present by 20 WAP. Shoot dry weight was greatest for plants irrigated every 2 d (675.5 g) compared to plants irrigated every 4 d (532.5 g) or every 8 d (501.1 g). Both plots received an additional 285.24 mm (11.23 in.) of rainfall.

Summary

Irrigation frequency had little if any impact on the growth of *I. cornuta* 'Burfordii Nana' in either the high or low water field plot. However, impacts on growth of *V. odoratissimum* grown in high and/or low water field plots were observed for the June 2006, Dec. 2006, and Sept. 2007 plantings. In general, growth decreased with irrigation frequency.

Study F. Lysimeter Study - Apopka, FL

Materials and Methods
Two species (*Viburnum odoratissimum* and *Ilex cornuta* 'Burfordii Nana') grown in 11.4 L containers were planted in two separate experimental plots (drainage lysimeters and a high water field plot) Nov. 2008 the Mid-Florida Research and Education Center in Apopka, FL. Shrubs installed in lysimeters were planted in 9 concrete drainage lysimeters (3.66 m x 4.57 m x 1.01 m deep) filled with native soil. Five plants of each species were spaced 1.8 m on center in each lysimeter. Shrubs installed in the companion field plot were planted and irrigation was installed as in study "A".

Regardless of planting location (lysimeters or field plot) shrubs received 9 L irrigation per irrigation event applied evenly to the entire soil surface within each lysimeter. Irrigation was applied to a similar surface area of shrubs planted in the field. Irrigation was applied at 3 irrigation frequencies (every 1, 2, or 4 d). All plants received an additional 11.43 cm of rainfall over the course of the experiment.

Volume of water draining from the bottom of the lysimeters was automatically recorded with digital flow meters attached to a data logger. Digital flow meters also automatically recorded irrigation volumes applied for each treatment. Climatic data was recorded during the study period to calculate reference evapotranspiration (ET_{ref}). Water budgets were calculated daily for each drainage lysimeter and compared with ET_{ref}. Tensiometer readings were recorded on a separate data logger. These readings were calibrated against irrigation frequencies and plant measurements.

Twenty weeks after planting, canopy height, widest canopy width, the width perpendicular to the widest width, and the maximum root extension were recorded and used to determine GI and canopy to root spread ratio as described in previous studies. Additionally, the entire above ground canopy (shoots) was harvested and two wedge-shaped sections of soil containing approximately ⅛ of the soil volume containing roots (extending beyond the trunk) were excavated. Canopy and root biomass were processed to remove soil and dried as in study "A". Total canopy dry weight, root dry weight, and canopy to root dry weight ratio was then calculated as in study "A".

The experiment was designed as a randomized complete block with 3 irrigation frequencies x 2 species x 3 replicates with 5 plants per replicates (lysimeter). Data for each species was analyzed separately. To ensure growth was similar in both experimental plots, locations were analyzed both separately and together. Shrub growth index, root spread, canopy dry weight, root dry weight, root dry weigh to canopy dry weight ratio and root to canopy spread ratio were analyzed using the PROC GLM procedure in SAS (SAS Institute, 2003) All pair-wise comparisons were completed using the Tukey test with a significance level of $\alpha = 0.05$.

Results and Discussion
When the experimental plots were analyzed separately, all growth parameters (i.e. shoot dry weight, root dry weight, growth index, shoot to root dry weight ratios, canopy spread, root spread, and root spread to canopy spread ratio) were similar among treatments in both locations (data not shown). Significant differences were found for *I. cornuta*

'Burfordii 'Nana' root spread and root spread to canopy spread ratios when locations were compared. Plants irrigated every 2 d had a higher root spread to canopy spread ratio and greater root spread (0.51 and 29.1 cm, respectively) than every 4 d, but were not different from plants receiving irrigation daily (0.48 and 25.7 cm, respectively). There was a location effect for *V. odoratissimum* root spread to canopy spread ratios. Lysimeter grown plants had a root to canopy spread ratio of 0.41 compared to 0.28 for field grown plants. No interactions between treatment and location were found.

However, significant differences in irrigation volumes, total application volumes (irrigation + rainfall), leachate, actual evapotranspiration (ETA), and average ETA were found among treatments for both species (Table 1). Daily irrigation of *I. cornuta* 'Burfordii Nana' resulted in 85% and 2.75× greater application volumes than irrigating every 2 or 4 d, respectively. Total volumes applied to *V. odoratissimum* were 1.08× and 2.84× greater with daily irrigation compared to 2 and 4 d frequencies, respectively. Similar results were found for leachate volumes.

It must be noted the ETA values presented are an estimate and not an accurate calculation of ETA. To accurately calculate ETA, the entire soil surface must be covered by the plant canopy. However, due to the short duration of the establishment project, 100% canopy cover was not achieved. Despite the limitations, the data indicates plants irrigated daily have higher ETA rates. The results are likely due to surface evaporation given that canopy sizes were similar among treatments. In future research, calculation of ETA rates from an established landscape (i.e. 100% canopy cover) for use in demand-based irrigation would be beneficial given the average lifespan of a mature landscape compared to the relatively short period of establishment.

Summary
Data presented indicate that shrubs can be irrigated every 4 d with growth equivalent to plants irrigated daily or every 2 d. This results in average reductions in applied irrigation of 76% and 51%, respectively.

Project Conclusions

Based on our results, we suggest that 11.4 L (3-gallon) container-grown shrubs can be successfully established by applying 3 L (0.8 gallons) of water per irrigation event to the root ball and soil adjacent to the root ball provided near normal rainfall occurs. Irrigation should be applied at a frequency of every 8 days in north and central Florida and every 4 days in south Florida for a period of 20 weeks after planting. However, optimal growth may be achieved during the first 2 years after planting when irrigation frequency in north and central Florida is increased to every 4 days and irrigation in south Florida is increased to every 2 days. Irrigating at least every 2 (south Florida) to 4 (central and north Florida) days is recommended for survival when planting during extended dry periods.

Although regular irrigation was discontinued by 12-28 weeks after planting (WAP) depending on project phase, supplemental irrigation was required in north, central, and south Florida during extended periods of dry weather as long as 2 years after planting

(Figure 1A, B and C). Additionally, the time needed to reach a root spread to canopy spread ratio of 1.0 when regular irrigation could be discontinued varied considerably between species from 12 to 104 WAP. The occasional need for supplemental irrigation and the variability in establishment rate between species suggest that irrigation needs during establishment are contingent upon species and rainfall conditions. Therefore, we recommend that all shrubs be monitored after regular irrigation is discontinued for symptoms of water stress for at least the first 2 years after planting.

Soil conditions at study plots were about ideal for plant growth and therefore wer not indicative of all residential and commercial landscape soils. Water requirements in real landscapes throughout Florida may vary with soil and microclimate conditions. Factors that could increase water requirements include soil compaction, excessive drainage, coarse texture, layered soil profiles, hardpans, restricted soil volume such as highway medians, high soil pH, proximity to a building, western exposure, slope, root bound plants, close proximity to established trees, and other factors. None of these were studied in this project.

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Tables

Table 1. Ten native and 11 non-native species used in phase two experiments in north, central, and south Florida; USDA hardiness zones 8b, 9a, and 10b respectively.

North Florida (hardiness zone 8b)	
Native	Non-native
Ilex vomitoria 'Schillings'	*Rhapiolepis indica*
Forestiera segregata	*Ligustrum japonicum*
Duranta erecta 'Sapphire'	*Gardenia jasminoides* 'Mystery'
Callicarpa americana	*Juniperus chinensis* 'Parsonii'
Viburnum obovatum 'Whorled Class'	*Viburnum suspensum*
Myrica cerifiera	*Loropetalum chinense rubrum* 'Ruby'
Central Florida (hardiness zone 9a)	
Native	Non-native
Forestiera segregata	*Rhapiolepis indica*
Hamelia patens	*Ligustrum japonicum*
Duranta erecta 'Sapphire'	*Jasminum multiflorum*
Ilex vomitoria 'Schillings'	*Gardenia jasminoides* 'Mystery'
Viburnum obovatum 'Whorled Class'	*Viburnum suspensum*
Myrcianthes fragrans	*Loropetalum chinense rubrum* 'Ruby'
South Florida (hardiness zone 10b)	
Native	Non-native
Myrcianthes fragrans	*Rhapiolepis indica*
Ilex vomitoria 'Schillings'	*Allamanda schotti*
Forestiera segregata	*Codiaeum variegatum*
Hamelia patens	*Hibiscus rosa-sinensis*
Conocarpus erectus var *seriacus*	*Jasminum multiflorum*
Chrysobalanus icaco	*Ixora* 'Nora Grant'

Table 2. Canopy and root measurements 52 weeks after May 2004 planting of *Viburnum odoratissimum* with 2 irrigation frequencies and 3 irrigation volumes.

Irrigation Frequency	Irrigation Volume	Canopy Growth (m^3)	Canopy Density[z]	Canopy Dieback[z]	Canopy Dry Weight[y] (g)	Root Spread Radius (cm)	Root Dry Weight[y] (g)	Root Spread Radius to Canopy Radius Ratio	Root Dry Weight to Canopy Dry Weight Ratio[y]
Every 2 d	3L	.66	97.00	143.50	1142.50	87.67	591.73	1.77	.53
Every 2 d	6L	.72	159.00	105.33	1156.57	93.17	477.87	1.81	.42
Every 2 d	9L	.62	97.00	105.33	1399.00	97.67	734.67	2.00	.53
Every 4 d	3L	.63	97.00	143.50	1151.47	97.00	488.67	2.01	.41
Every 4 d	6L	.67	128.00	105.33	1099.00	96.83	514.27	1.88	.47
Every 4 d	9L	.53	74.33	143.50	1127.97	88.50	446.30	1.86	.37

	Canopy Growth	Canopy Density	Canopy Dieback	Canopy Dry Weight	Root Spread Radius	Root Dry Weight	Root Spread Radius to Canopy Radius Ratio	Root Dry Weight to Canopy Dry Weight Ratio
Irrigation Frequency	.58	.30	.56	.38	.89	.16	.73	.32
Irrigation Volume	.38	.01*[x]	.37	.49	.74	.42	.69	.91
2 vs 4 d with 3 L	.85	0	0	.96	.31	.51	.21	.40
2 vs 4 d with 6 L	.74	.48	1.0	.77	.69	.61	.52	.60
2 vs 4 d with 9 L	.37	.32	.32	.24	.51	.23	.64	.15

[z] Density and dieback means were generated by the Proc RANK procedure in SAS.
[y] Biomass measurements were recorded 64 weeks after planting.
[x] Significance of treatment effects and interactions *(*P* < 0.05) ** (*P* < 0.01).

Table 3. Canopy and root measurements 52 weeks after May 2004 planting of *Ilex cornuta* 'Burfordii Nana' with 2 irrigation frequencies and 3 irrigation volumes.

Irrigation Frequency	Irrigation Volume	Canopy Growth (m^3)	[z]Canopy Density	[z]Canopy Dieback	Canopy Dry Weight[y] (g)	Root Spread Radius (cm)	Root Dry Weight[y] (g)	Root Spread to Canopy Spread Ratio	Root Dry Weight to Canopy Dry Weight Ratio[y]
Every 2 d	3L	.19	128.00	143.50	968.93	73.17	287.87	1.83	.29
Every 2 d	6L	.14	128.00	105.33	868.57	61.83	195.87	1.62	.22
Every 2 d	9L	.16	128.00	143.50	943.60	77.33	325.33	1.98	.34
Every 4 d	3L	.11	97.00	58.50	717.13	76.17	189.07	2.21	.26
Every 4 d	6L	.11	74.33	67.17	781.97	47.33	167.02	1.25	.24
Every 4 d	9L	.14	128.00	96.67	799.33	79.83	161.02	2.05	.23

	Canopy Growth	Canopy Density	Canopy Dieback	Canopy Dry Weight	Root Spread Radius	Root Dry Weight	Root Spread Radius to Canopy Radius Ratio	Root Dry Weight to Canopy Dry Weight Ratio
Irrigation Frequency	.22	.20	.04*[x]	.10	.69	.32	.89	.67
Irrigation Volume	.55	.61	.61	.78	.002**	.58	.01*	.57
2 vs 4 d with 3 L	.05	.32	.08	.08	.62	.52	.16	.86
2 vs 4 d with 6 L	.57	.05	.32	.12	.27	.70	.37	.68
2 vs 4 d with 9 L	.69	1.0	.32	.37	.82	.19	.70	.14

[z] Density and dieback means were generated by the Proc RANK procedure in SAS.
[y] Biomass measurements were recorded 64 weeks after planting.
[x] Significance of treatment effects and interactions *(P < 0.05) ** (P < 0.01).

Table 4. Mean growth index for *V. odoratissimum* irrigated every 2, 4, or 8 d averaged over 8 planting dates over a 2 year period in north, central, and south Florida (USDA hardiness zones 8b, 9a, and 10b).

Irrigation frequency	Growth index[z] (m^3)		
	28 WAP[y]	52 WAP	104 WAP
	Hardiness zone 8b (north Florida)		
2 d	0.42a[x]	0.91a	4.01a
4 d	0.32b	0.78a	3.33b
8 d	0.32b	0.75a	3.24b
	Hardiness zone 9a (central Florida)		
2 d	0.42a	0.68a	2.52a
4 d	0.39ab	0.70a	2.10ab
8 d	0.35b	0.59a	1.87b
	Hardiness zone 10b (south Florida)		
2 d	0.51a	0.71a	2.96a
4 d	0.50a	0.80a	3.20a

[z]Growth index = height × width 1 × width 2.
[y]WAP = week after planting
[x]Mean separations within a column and hardiness zone using Tukey, $P = 0.05$.

Table 5. Mean root spread radius and root to canopy spread ratio for *V. odoratissimum* irrigated every 2, 4, or 8 d averaged over 8 planting dates over a 2 year period in north, central, and south Florida (USDA hardiness zones 8b, 9a, and 10b).

Irrigation frequency	Root spread radius (cm)			Root:canopy spread ratio[z]		
	28 WAP[y]	52 WAP	104 WAP	28 WAP	52 WAP	104 WAP
	Hardiness zone 8b (north Florida)					
2 d	56.6a[x]	95.4a	130.9a	1.5a	1.9a	1.6a
4 d	52.5a	92.9a	130.7a	1.5a	2.0a	1.7a
8 d	51.9a	88.6a	127.2a	1.5a	2.0a	1.6a
	Hardiness zone 9a (central Florida)					
2 d	35.7a	55.4a	67.4a	1.0a	1.3a	1.0a
4 d	38.6a	58.2a	64.7a	1.0a	1.3a	1.1a
8 d	39.5a	57.2a	63.4a	1.1a	1.4a	1.1a
	Hardiness zone 10b (south Florida)					
2 d	34.6a	92.5a	152.5a	1.0b	2.2a	3.0a
4 d	40.8a	61.5b	105.8b	1.2a	1.4b	1.6b

[z]Root to canopy spread ratio = root spread radius / [¼ × (canopy width 1 + width 2)].
[y]WAP = week after planting
[x]Mean separations within a column and hardiness zone using Tukey, $P = 0.05$.

Table 6. Mean root extension to canopy spread ratio, shoot dry weight, and root dry weight at 52 and 104 WAP for *P. nervosa* (wild coffee) and *M. paniculata* (orange jasmine) irrigated every 2, 4, or 8 d with 3 L of water.

Irrigation Frequency (d)	Root extension to canopy spread ratio		Shoot dry weight (g)		Root dry weight (g)	
	52 WAP	104 WAP	52 WAP	104 WAP	52 WAP	104 WAP
			Wild coffee			
2	0.59a	0.85a	237a[z]	436a	317a	506a
4	0.59a	0.87a	195ab	468a	318a	515a
8	0.72a	0.90a	170b	439a	273a	477a
			Orange jasmine			
2	0.92a	1.07a	1041a	3487a	729a	1764a
4	1.00a	1.13a	1057a	3341a	723a	1645a
8	0.92a	1.12a	897b	3190a	698a	1443a

[z]Mean separations within columns and species using Tukey, $P = 0.05$, N = 12

Table 7. Dry shoot and root biomass for *V. odoratissimum* irrigated every 2, 4, or 8 d averaged over 8 planting dates over a 2 year period in north, central, and south Florida (USDA hardiness zones 8b, 9a, and 10b).

Irrigation frequency	Shoot biomass (g)		Root biomass (g)	
	52 WAP[z]	104 WAP	52 WAP	104 WAP
	Hardiness zone 8b (north Florida)			
2 d	820a[y]	4367a	458a	955a
4 d	685ab	3653ab	298a	892a
8 d	630b	3373b	329a	904a
	Hardiness zone 9a (central Florida)			
2 d	817a	2789a	874a	626a
4 d	751a	3079a	738a	543a
8 d	726a	2186a	687a	487a
	Hardiness zone 10b (south Florida)			
2 d	664a	1496a	870a	1642a
4 d	401b	1197a	592b	846b

[z]WAP = week after planting

[y]Mean separations within a column and hardiness zone using Tukey, $P = 0.05$.

Table 8. Shoot and root dry biomass for *I. cornuta* 'Burfordii Nana' irrigated every 2, 4, or 8 d averaged over 8 planting dates over a 2 year period in north and central, Florida (USDA hardiness zones 8b and 9a).

Irrigation frequency	Shoot biomass (g)		Root biomass (g)	
	52 WAP[z]	104 WAP	52 WAP	104 WAP
	Hardiness zone 8b (north Florida)			
2 d	551a[y]	1669a	193a	474a
4 d	466b	1420b	161a	432a
8 d	481b	1450b	168a	470a
	Hardiness zone 9a (central Florida)			
2 d	512a	1366a	551a	681a
4 d	488a	1274a	577a	734a
8 d	489a	1301a	577a	822a

[z]WAP = weeks after planting.

[y]Mean separations within column and location using Tukey, $P = 0.05$.

Table 9. Shoot and root dry biomass for *P. tobira* 'Variegata' irrigated every 2, 4, or 8 d averaged over 8 planting dates over a 2 year period in north and central Florida (USDA hardiness zones 8b and 9a).

Irrigation frequency	Shoot biomass (g)		Root biomass (g)	
	52 WAP	104 WAP	52 WAP	104 WAP
	Hardiness zone 8b (north Florida)			
2 d	485a	2029a	130a	267a
4 d	449ab	1657b	138a	272a
8 d	387b	1599b	108a	303a
	Hardiness zone 9a (central Florida)			
2 d	617a	1851a	537a	649a
4 d	612a	2278a	548a	704a
8 d	605a	1653a	503a	613a

[z]Mean separations within column and location using Tukey, $P = 0.05$.

Table 10. Mean root lengths for *Ilex cornuta* 'Burfordii Nana', *Pittosporum tobira* 'Variegata', and *Viburnum odoratissimum* irrigated at three frequencies (2, 4, or 7 d) over a 6-month period during late summer to early spring in central Florida.

Species	Irrigation frequency	Root length (cm)[z]
Ilex cornuta 'Burford Nana'	2-day	45.56 a[yx]
	4-day	41.06 a
	7-day	35.00 b
Pittosporum tobira 'Variegata'	2-day	44.84 a
	4-day	33.08 b
	7-day	29.94 b
Viburnum odorotissimum	2-day	52.13 a
	4-day	41.00 b
	7-day	18.69 c

zRoot lengths were measured outside the root ball of the harvested segment.
yMeans calculated from four single plant replicates.
xMean separations within column and species using Fisher protected LSD ($P < 0.05$).

Table 11. Growth measurements for *Pittosporum tobira* 'Variegata' and *Viburnum odoratissimum* irrigated every 2, 4, or 7 d over a 6-month period during late summer to early spring in central Florida.

Species	Irrigation frequency	Leaf area (cm^2)	Shoot dry wt. (g)	New root dry wt. (g)	Total root dry wt. (g)	Biomass (g)	Growth index[z] (m^3)
Pittosporum tobira 'Variegata'	2-day	8711 a[y]	303.9 a	27.14[NS]	76.89[NS]	380.8 a	0.17 a
	4-day	5696 b	191.5 b	17.79	72.79	264.3 b	0.12 b
	7-day	5256 b	200.3 b	8.21	52.86	253.2 b	0.11 b
Viburnum odorotissimum	2-day	9896 a[z]	316.9 a	115.99 a	155.39 a	472.3 a	0.37[NS]
	4-day	6488 ab	203.7 ab	50.67 b	95.32 b	299.0 ab	0.24
	7-day	1583 b	84.9 b	8.22 b	63.22 b	148.1 b	0.13

[z]Growth index = height · width 1 · width 2.
[y]Means representative of four single plant replicates.
[x]Mean separations within columns and species using Fisher protected LSD ($P = 0.05$).
[NS]Nonsignificant.

Table 12. Mean daily leaf gas exchange (g_s) recorded monthly on the day before irrigation (stressed) and irrigation day (unstressed) for shrub species irrigated every 2, 4, or 7 d over a 6-month period during late summer to early spring in central Florida.

		[v]G_S (mmol_m–2)			
		Weeks after transplanting			
Species	Stress Day	8	12	16	20
Ilex cornuta 'Burford Nana'	Unstressed	248.1 a[z,y]	146.6 b	178.8^{NS}	181.8^{NS}
	Stressed	155.1 b	229.3 a	166.7	160.3
Pittosporum tobira 'Variegata'	Unstressed	125.9 a	68.8 b	120.7 a[x]	127.8 a
	Stressed	57.2 b	109.5 a	83.3 b	98.3 b
Viburnum odorotissimum	Unstressed	143.9^{NS}	94.7^{NS}	119.4^{NS}	127.8^{NS}
	Stressed	104.2	121.8	94.8	98.3

		G_S (mmol_m–2)			
		Weeks after transplanting			
Species	Irrigation Frequency	8	12	16	20
Ilex cornuta 'Burford Nana'	2-Day	220.2^{NS}	253.2 a	188.1^{NS}	181.9^{NS}
	4-Day	184.4	177.3 b	148.6	180.3
	7-Day	200.1	133.4 c	181.7	150.9
Pittosporum tobira 'Variegata'	2-Day	127.4 a	147.5 a	152.5 a[w]	171.4 a
	4-Day	85.0 b	59.3 b	95.9 b	117.1 b
	7-Day	62.3 c	60.8 b	57.5 c	50.9 c
Viburnum odorotissimum	2-Day	199.4 a	163.3 a	128.5 a	171.1^{NS}
	4-Day	80.7 b	65.1 b	87.3 c	117.1
	7-Day	81.3 b	84.5 b	100.7 b	50.9

[z]Means calculated from four single plant replicates.
[y]Mean separations within columns and species using Fisher protected LSD ($P < 0.05$).

[x]Values represent pooled g_s irrigation frequency treatment means on the stressed and unstressed days; however, stress day effect cannot be clearly identified due to a significant irrigation frequency · stress day interaction, $P < 0.05$.
[w]Values represent pooled g_s stress day means for each irrigation frequency treatment; however, irrigation frequency effect cannot be clearly identified as a result of a significant irrigation frequency · stress day interaction ($P < 0.05$).
[NS]Nonsignificant.
[v]Leaf gas exchange measurements were taken on two leaves on each plant during each sampling period with a steady state porometer.

Table 13. Cumulative daily water stress integrals (S_Ψ) calculated monthly on the day before irrigation (stressed) and irrigation day (unstressed) for shrub species irrigated every 2, 4, or 7 d over a 6-month period during late summer to early spring in central Florida.

		Predawn Ψ (MPa)				
		Weeks after transplanting				
Species	Stress Day	8	12	16	20	24
Pittosporum tobira 'Variegata'	Unstressed	0.16 b[zy]	0.05 b	0.15[NS]	0.22[NS]	0.18[NS]
	Stressed	0.55 a	0.18 a	0.12	0.15	0.24
Viburnum odorotissimum	Unstressed	0.20 b	0.07 b	0.17[NS]	0.09[NS]	0.06[NS]
	Stressed	0.36 a	0.24 a	0.12	0.09	0.07

		[w]Cumulative water potential, S_Ψ (MPa h–1)				
		Weeks after transplanting				
Species	Stress Day	8	12	16	20	24
Pittosporum tobira 'Variegata'	Unstressed	2.71 b	2.29 b	4.04[NS]	4.48[NS]	4.89 b
	Stressed	8.45 a	4.18 a	4.26	6.55	7.49 a
Viburnum odorotissimum	Unstressed	2.95 b[x]	3.89 b	3.06[NS]	4.15[NS]	3.66[NS]
	Stressed	10.38 a	8.94 a	5.95	5.58	3.93

[z]Means calculated from four single plant replicates.
[y]Mean separations within columns and species using Fisher protected LSD ($P < 0.05$).
[x]Values represent pooled Sy irrigation frequency treatment means on the stressed and unstressed days; however, stress day effect cannot be clearly identified as a result of a significant irrigation frequency · stress day interaction ($P < 0.05$).
[NS]Nonsignificant.
[w]Cumulative daily water stress integrals (S_Ψ) were calculated as described by Schulze et al. (1980) and Beeson (1992).

Table 14. Plant quality^{z} for *Viburnum odorotissimum* irrigated every 2, 4, or 7 d.

	Weeks after transplanting					
Irrigation frequency	4	8	12	16	20	24
2-day	4.4 a	3.8 a^{yx}	4.5 a	4.6 a	4.3 a	4.2 a
4-day	3.5 b	3.3 ab	3.6 a	3.2 a	3.2 a	3.3 a
7-day	1.8 c	1.8 b	1.5 b	1.5 b	1.5 b	1.5 b
P value	0.0002	<0.05	0.0075	0.0044	0.008	0.0075

^{z}Plants were rated monthly on a scale of 1 (dead) to 5 (mounded, proportional form; dense; complete coverage, no dieback).
^{y}Means calculated from four single plant replicates.
^{x}Mean separations within columns using Fisher protected LSD ($P < 0.05$).

Table 15. Growth measurements for *Ilex cornuta* 'Burford Nana' and *Viburnum odoratissimum* irrigated with three frequencies (2, 4 or 8 day) at 3 liters per irrigation event over a 6 month period during mid summer to late fall in central Florida (Summer 2007).

Species	Irrigation Frequency	Growth index^{z} (m^3)	Shoot dry weight (g)	Root dry weight (g)	Shoot to root dry weight ratio
Ilex cornuta 'Burford Nana'	2-day	0.21^{nsyx}	322.4 a	68.48^{ns}	4.71 a
	4-day	0.12	254.1 b	66.38	3.81 b
	8-day	0.16	244.9 b	65.42	3.73 b
	p-value	>0.05	0.03	>0.05	0.023
Viburnum odoratissimum	2-day	0.29^{ns}	314.0 a	36.94 a	8.49 a
	4-day	0.25	242.6 b	35.32 a	6.85 b
	8-day	0.13	172.0 c	31.93 b	5.37 b
	p-value	>0.05	0.007	0.009	0.014

^{z}Growth index = height × width 1 × width 2.
^{y}Means representative of 3 single plant replicates.
^{x}Mean separations within columns using Fisher Protected LSD, P=0.05.
^{ns}Non-significant.

Table 16. Growth measurements for *Viburnum odoratissimum* irrigated with three frequencies (1, 2, or 4 day) at 9 liters per irrigation event over a 6 month period during early winter to late spring in central Florida (Winter 2007).

Irrigation Frequency	Growth index[z] (m^3)	Shoot dry weight (g)	Root dry weight (g)	Canopy spread[y] (12 WAP)	Canopy spread (20 WAP)
1-day	0.96 a[xw]	925.7 a	164.9[ns]	32.50 a	40.83 a
2-day	0.76 a	903.5 a	165.6	31.08 ab	37.08 b
4-day	0.46 b	630.6 b	172.4	29.08 b	30.17 c
p-value	0.008	0.01	>0.05	0.028	0.0003

[z]Growth index = height × width 1 × width 2.
[y]Canopy spread = (width 1 + width 2) × 0.25
[x]Means representative of 3 single plant replicates.
[w]Mean separations within columns using Fisher Protected LSD, *P*=0.05.
[ns]Non-significant.
WAP = Weeks after transplant.

Figures

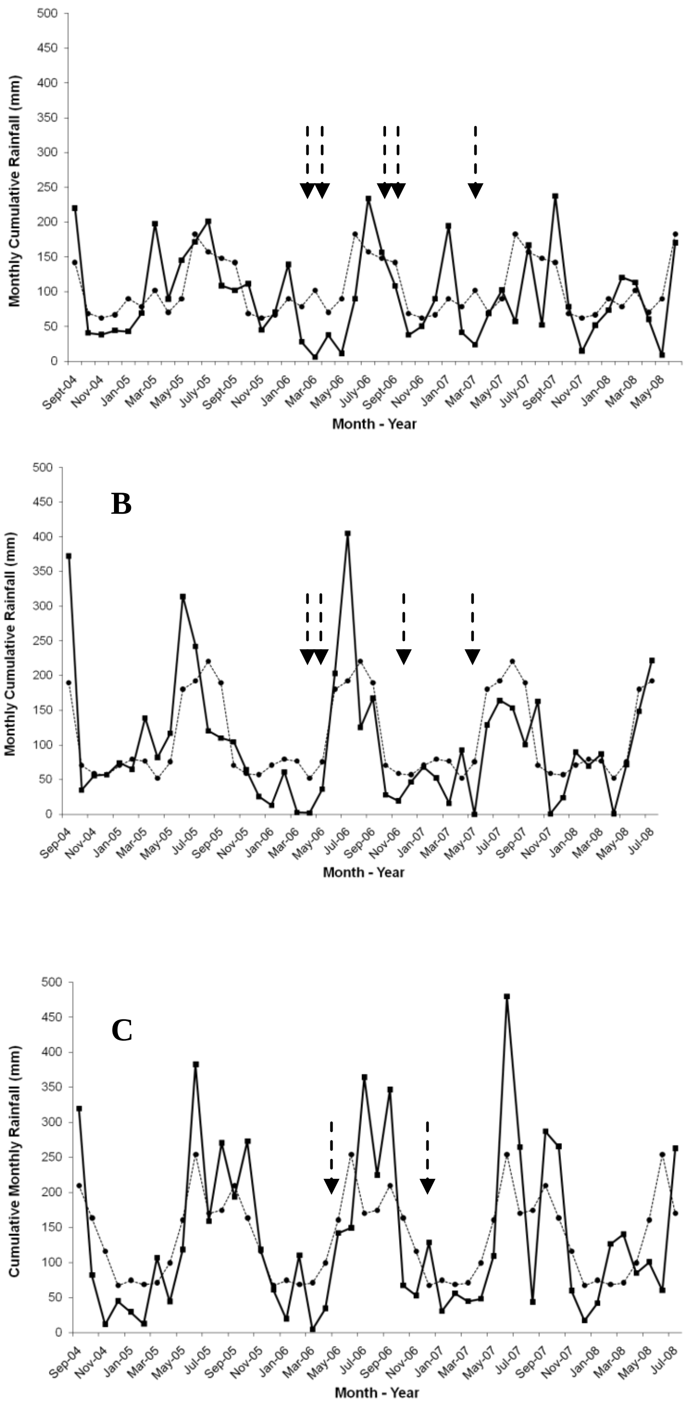

Figure 1. Actual cumulative monthly rainfall (solid line), historical monthly rainfall (dashed line), and supplemental irrigation applications (dashed arrows) received by field planted *V. odoratissimum* in USDA hardiness zone a) 8b (Citra, FL), b) 9a (Balm, FL) and c) 10b (Fort Lauderdale, FL).

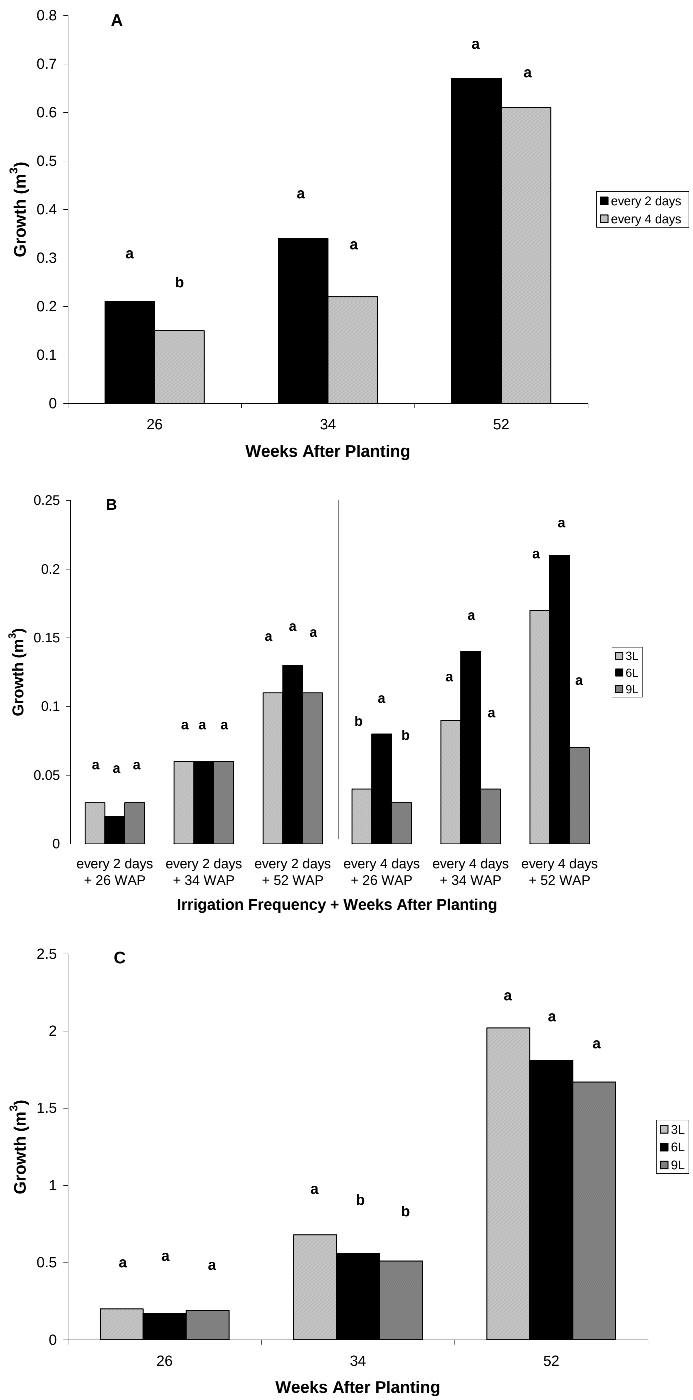

Figure 2. Significant main effects and interactions on canopy growth of *Viburnum odoratissimum* (A, C) and *Ilex cornuta* 'Burfordii Nana' (B). Letters denote significant differences (P< 0.05) between irrigation frequencies (A), volumes (C) or among irrigation volumes within a frequency and week after planting (B) at 26, 34, or 52 weeks after planting in May (A) or November (B, C).

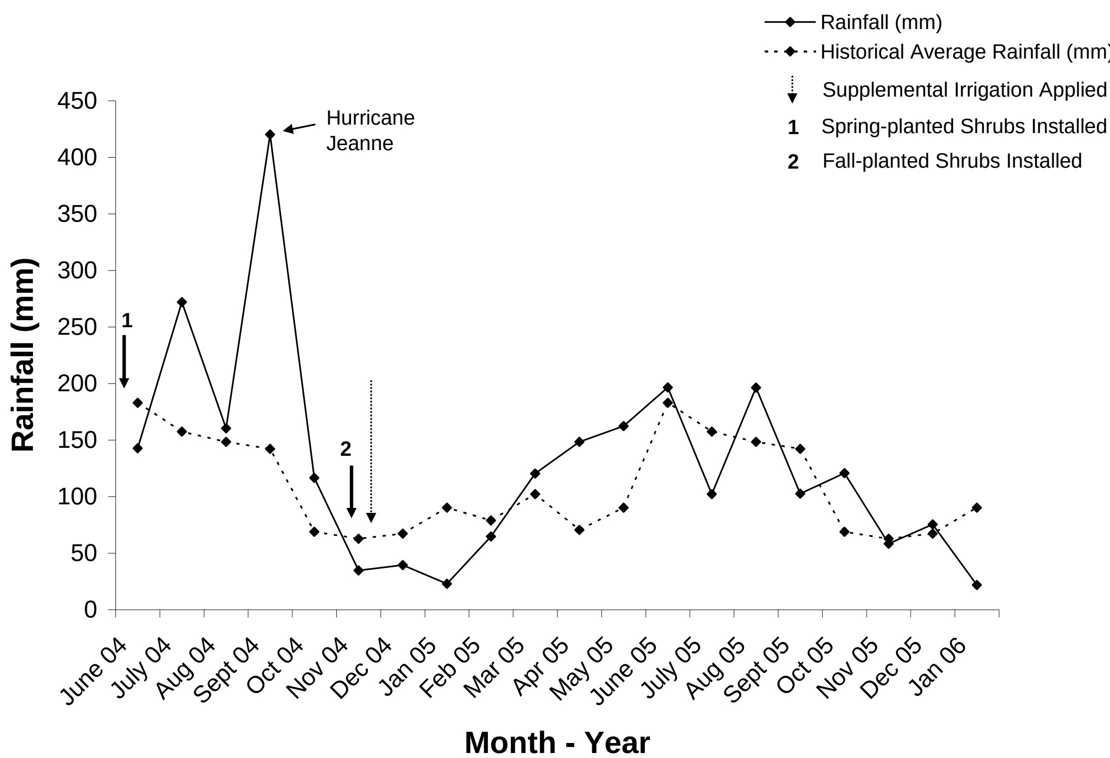

Figure 3. Actual monthly rainfall June 2004 through January 2006 and historical average monthly rainfall. Arrows (↓) indicate planting dates (May 27, 2004; November 16, 2004).

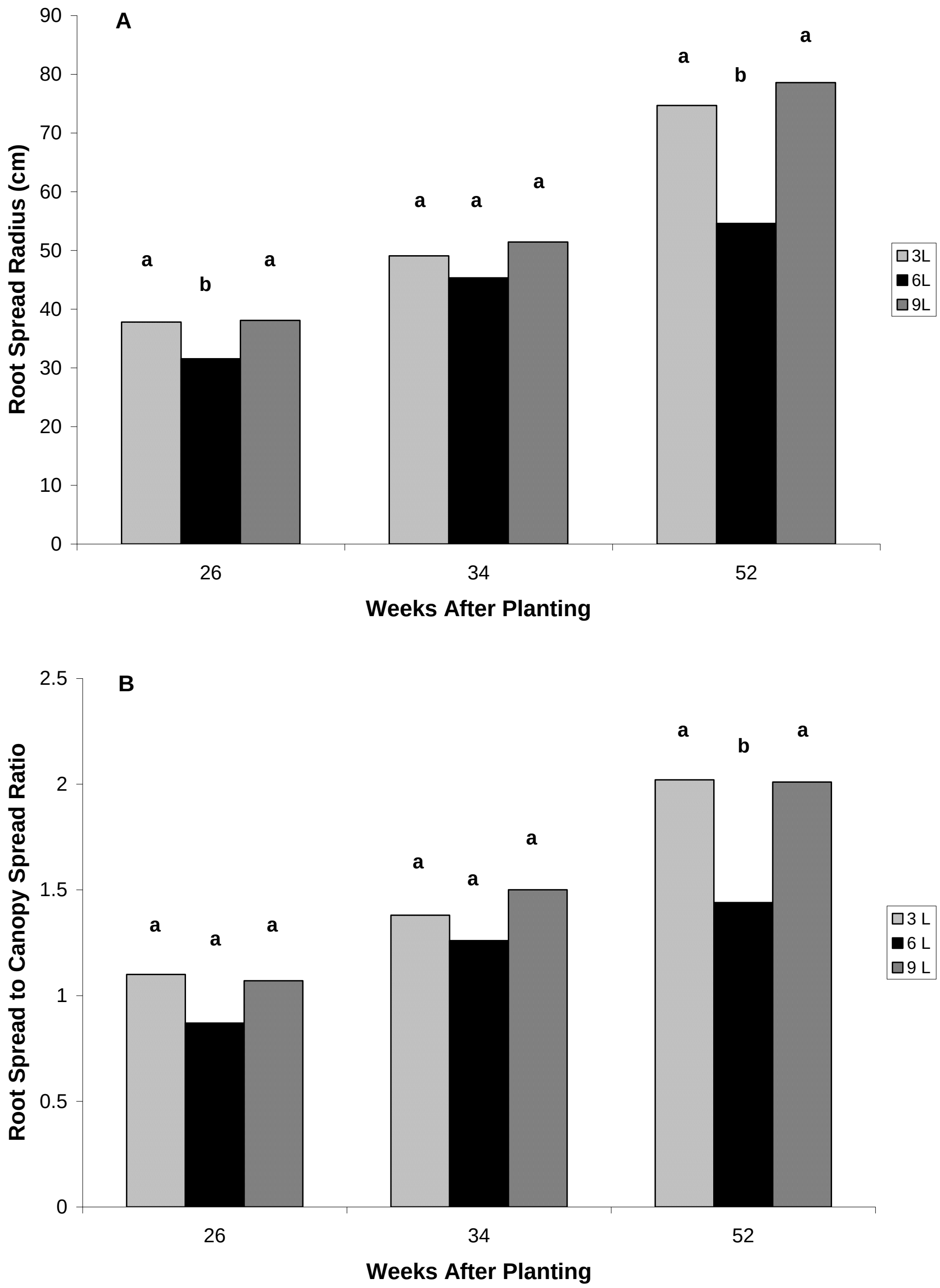

Figure 4. Effects of irrigation volume on root spread radius (A) and root spread to canopy spread ratio (B) of *Ilex cornuta* 'Burfordii Nana' 26, 34, or 52 weeks after planting in May 2004. Means for each week with the different letters are significantly different ($P < 0.05$).

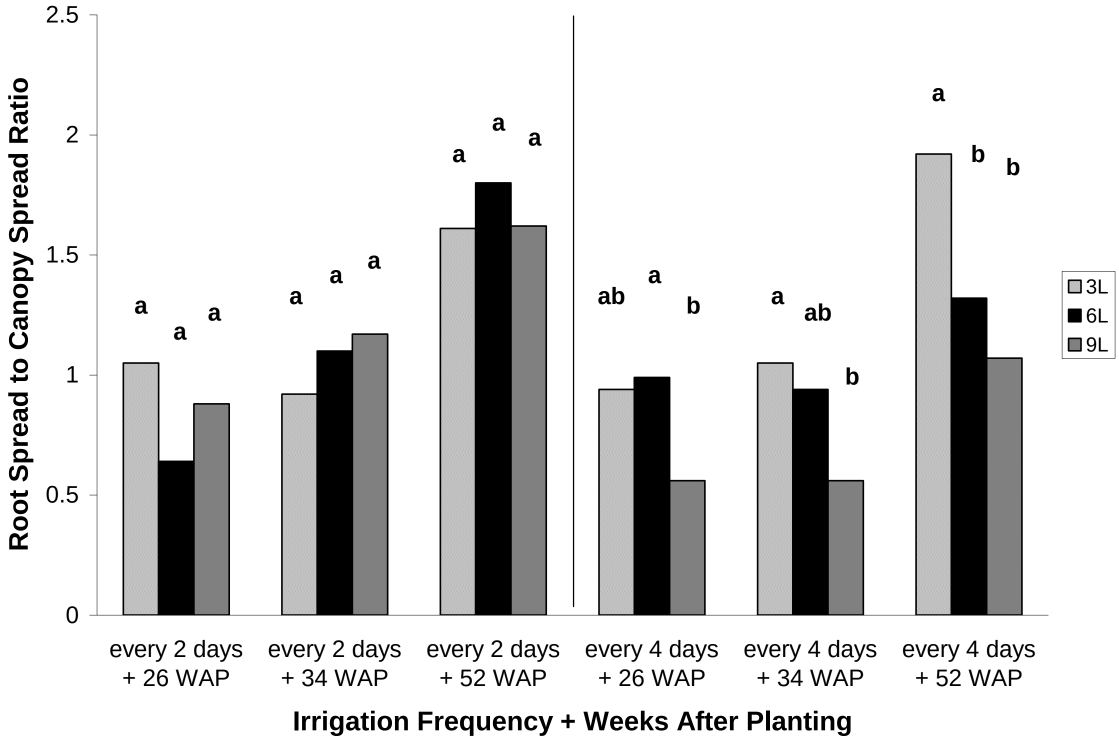

Figure 5. Root spread to canopy spread ratio for *Ilex cornuta* 'Burfordii Nana' planted in November 2004 and maintained with two frequencies and three volumes of irrigation. Means within an irrigation frequency for each time (WAP) with different letters are significantly different (*P*>0.05).

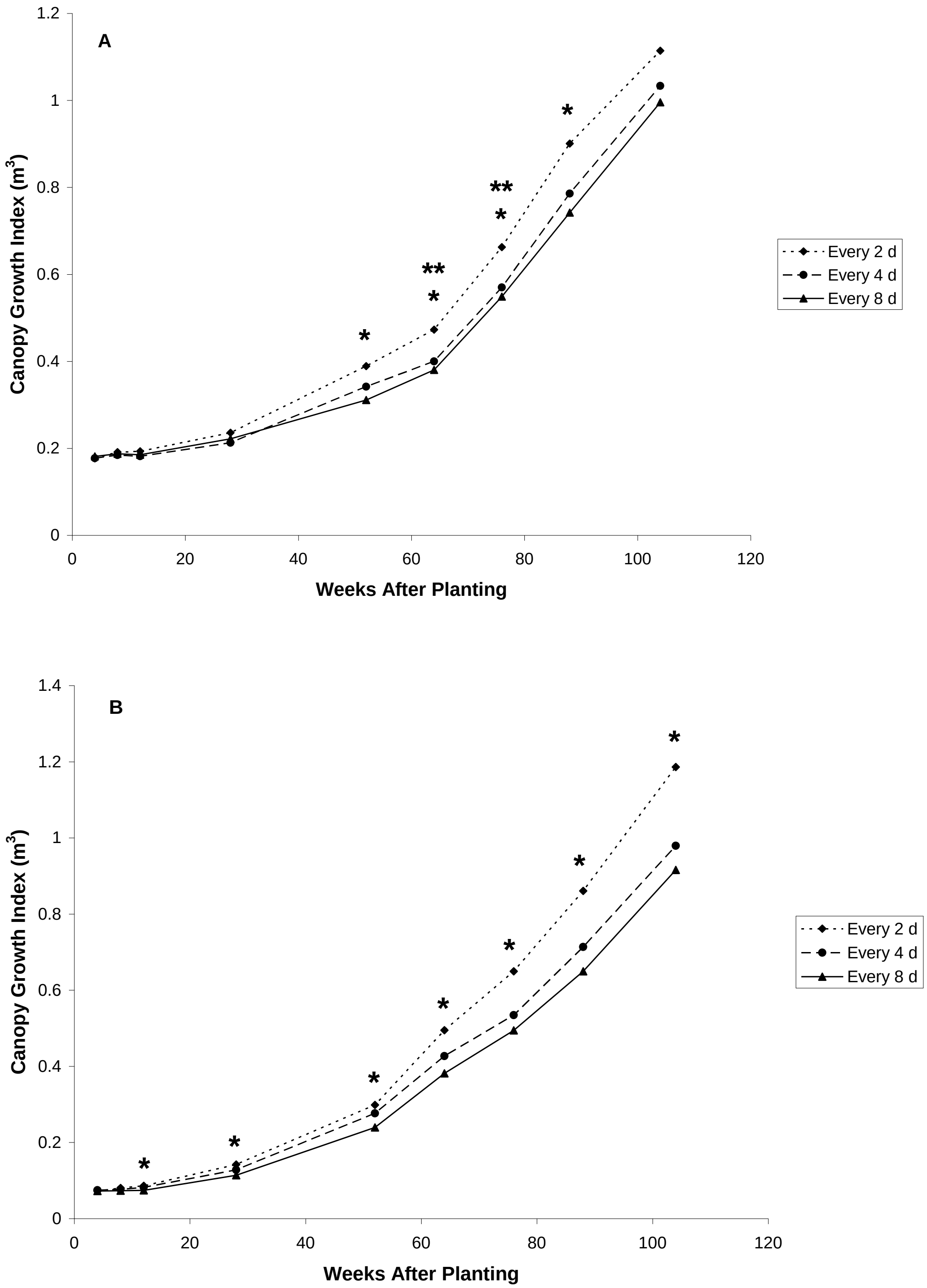

Figure 6. Canopy growth index 4 to 104 WAP of *I. cornuta* ‘Burfordii Nana’ (A) and or *P. tobira* ‘Variegata’ (B) averaged across 8 planting dates in north Florida (hardiness zone 8b, Citra, FL). Star (*) indicates significant difference ($P < 0.05$) between every 2d and every 8 d irrigation frequency treatments. Double star (**) indicates significant difference ($P < 0.05$) between every 2 d and every 4 d irrigation frequency treatments.

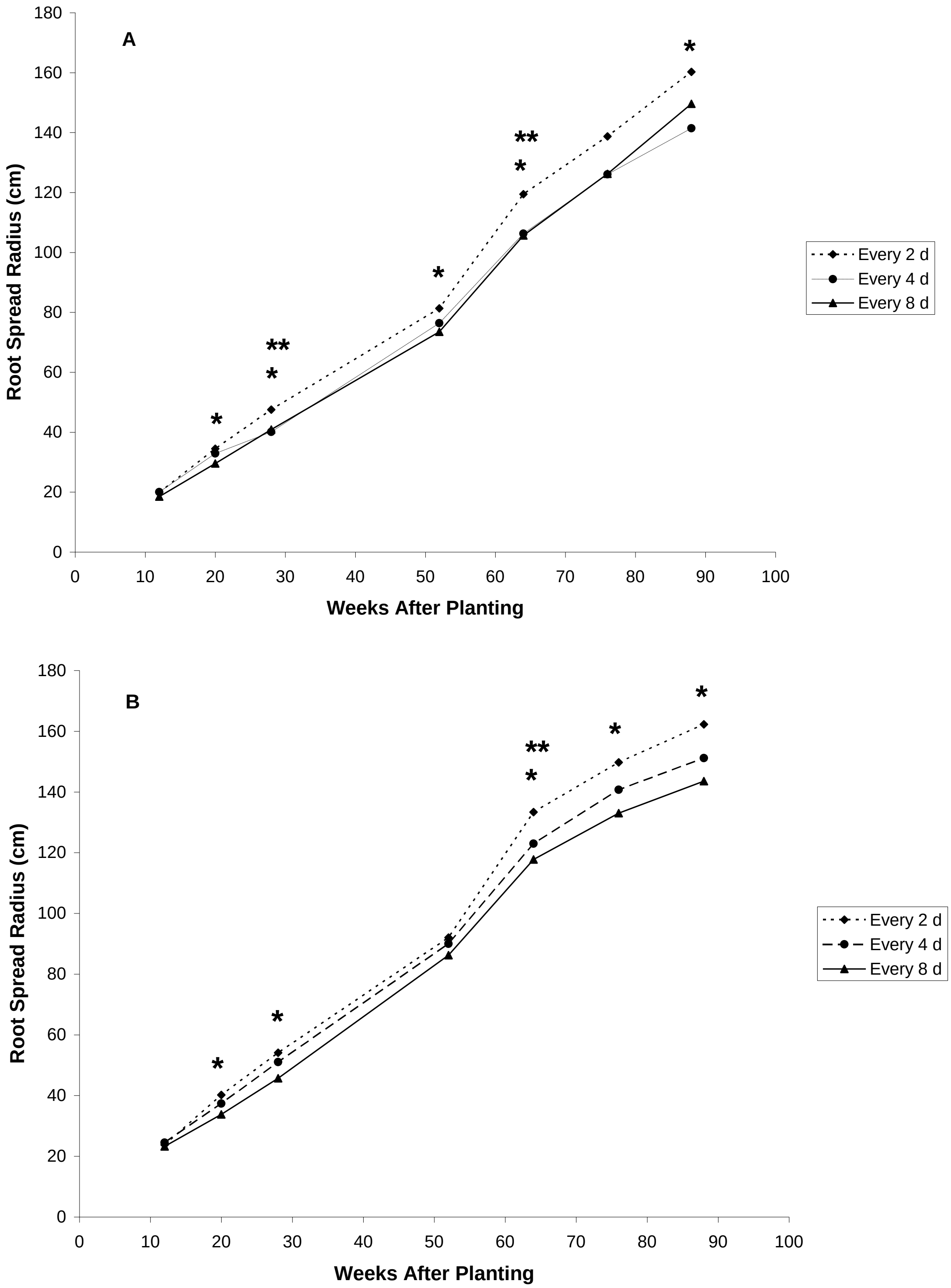

Figure 7. Root spread radius 12 to 88 WAP of *I. cornuta* ‘Burfordii Nana’ (A) and or *P. tobira* ‘Variegata’ (B) averaged across 8 planting dates in north Florida (hardiness zone 8b, Citra, FL). Star (*) indicates significant difference ($P < 0.05$) between every 2d and every 8d irrigation frequency treatments. Double star (**) indicates significant difference ($P < 0.05$) between every 2 d and every 4 d irrigation frequency treatments.

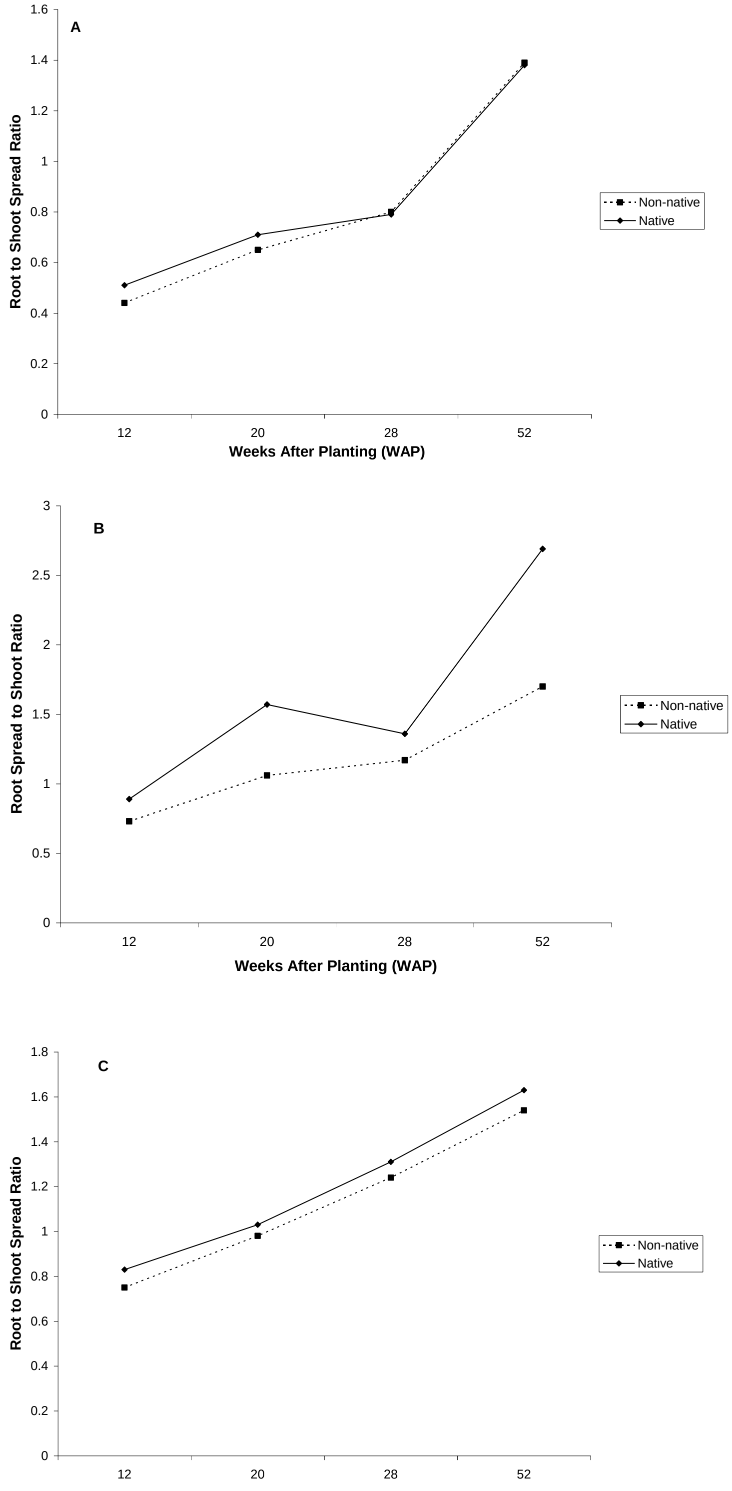

Figure 8. Mean root to shoot spread ratio of 12 native and non-native shrub species in hardiness zones 8b (B), 9a (A), and 10b (C) in Florida.

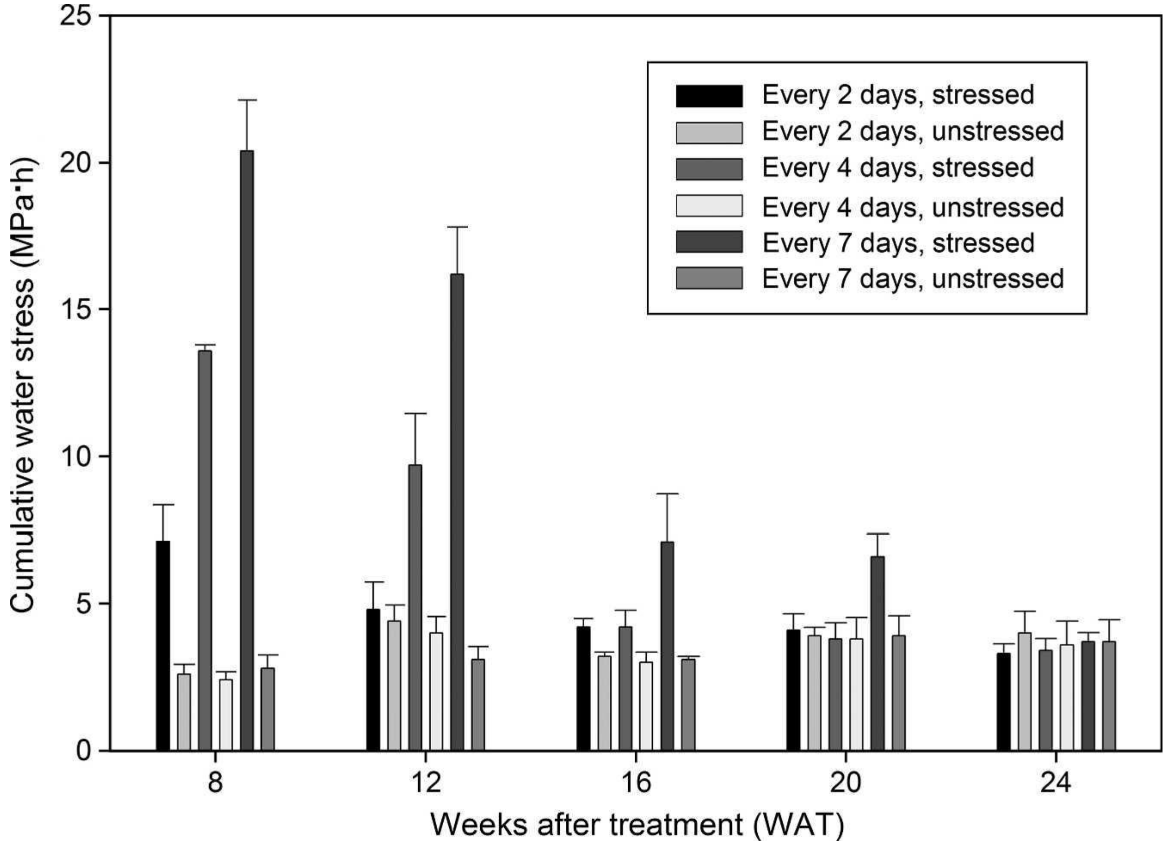

Figure 9. Cumulative daily water stress integrals (S_{Ψ}) calculated monthly on the day before irrigation (stressed) and irrigation day (unstressed) for *Ilex cornuta* ‘Burford Nana’ irrigated with three frequencies (2, 4, or 7 d) over a 6-month period during late summer to early spring in central Florida. Each bar represents the mean of four shrubs, whereas the vertical lines represent the SE.

<u>Appendix</u>

Publications resulting from this project:

Gilman, Edward F., Amy Shober, Kimberly A. Moore, Christine Wiese, Maria Paz. 2009. Planting shrubs in Florida landscapes. Univ. Florida Inst. Food Agric. Sci., Gainesville, FL. *In Press*.

Gilman, Edward F., Amy L. Shober, Kimberly A. Moore, Christine Wiese, Maria Paz, S. Michelle Scheiber. 2009. Establishing shrubs in Florida landscapes. Univ. Florida Inst. Food Agric. Sci., Gainesville, FL. *In Press*.

Gilman, E.F. C.L. Wiese, M. Paz, A. L. Shober, S.M. Scheiber, K.A. Moore, M. Brennan. 2009. Effects of Irrigation Volume and Frequency on Shrub Establishment in the Landscape. J. Environ. Hort. *In Press*.

Moore, K.A., A.L. Shober, E. F. Gilman, C. Wiese , S.M. Scheiber, M Paz, and M.M. Brennan. 2009. Growth of Wild Coffee, Copperleaf, and Orange Jasmine is Affected by Irrigation Frequency. HortTechnology. *Accepted for Publication*.

Scheiber, S.M., E.F. Gilman, M. Paz, and K.A., Moore. 2007. Irrigation Affects Landscape Establishment of Burford Holly, Pittosporum, and Sweet Viburnum. HortScience 42(2):344-348.

Shober, A.L., K.A. Moore, C. Wiese, S.M. Scheiber, E. F. Gilman, M. Paz, M.M. Brennan and S. Vyapari. 2009. Irrigation Frequency Affects Growth of Sweet Viburnum during Landscape Establishment in Three Hardiness Zones. HortScience. *Accepted for Publication*.

Wiese, C.L., A.L. Shober, E.F. Gilman, M. Paz, K.A. Moore, S.M. Scheiber, M.M. Brennan, and S. Vyapari. 2009. Effects of Irrigation Frequency During Establishment on the Growth of Ilex cornuta 'Burfordii Nana' and Pittosporum tobira 'Variegata'. HortScience. *Accepted for Publication*.